VŠB – Technical University of Ostrava

Faculty of Mechanical Engineering

Department of Energy Engineering

Solar system for a family house for hot water preparation and swimming pool pre-heating.

Solární soustava pro rodinný dům pro přípravu teplé vody a přihřívání bazénu

Student: Deepak Balaji

Diploma thesis supervisor: Ing. Ondřej Němček, Ph. D

Ostrava 2019

VŠB - Technical University of Ostrava
Faculty of Mechanical Engineering
Department of Energy Engineering

Diploma Thesis Assignment

Student: **Deepak Balaji, BE**

Study Programme: N2301 Mechanical Engineering

Study Branch: 2302T006 Energy Engineering

Title: Solar System for a Family House for Hot Water Preparation and Swimming Pool Pre-heating
Solární soustava pro rodinný dům pro přípravu teplé vody a přihřívání bazénu

The thesis language: English

Description:

Design and calculate solar system for specified family house for preparation of hot water with use of thermosolar collectors. House is situated in Ostrava, it is inhabited whole-year by 3 persons. Overproduction from solar collectors will be used in outdoor swimming pool. Solar coverage of heat demand for preparation of hot water – choose between 50 to 60 %.

Thesis will include:

1. Research focused on the possibilities of using solar radiation in the Czech Republic for the heat generation.
2. Design of the system, way of it use and operation, solution of disposition.
3. Determination of monthly and yearly profits based on a model processed using the database of a typical climate year. Do the optimisation of collector slope.
4. Evaluation of the proposal from an economic and environmental point of view.
5. Bilance comparisons of the same system and designing possible optimization adjustments for operating the system in a selected location in India.
6. Graphic part - schema of engagement, solution of disposition.

References:

GODFREY, B. et al.: Renewable energy. Oxford: Oxford University Press, 2004. 452 p. ISBN 0-19-926178-4.
HEINLOTH, K. (editor). Energy Technologies. Subvolume C: Renewable Energy. Springer-Verlag Berlin Heidelberg 2006. ISBN-10 3-540-42962-x.
SORENSEN, B.: Renewable Energy. Burlington: Elsevier Academic Press, 2004. 952 p. ISBN 0126561532.
Materials and blueprints, tables and technical documentation.

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

Supervisor: **Ing. Ondřej Němček, Ph.D.**

Date of issue: 21.12.2018

Date of submission: 20.05.2019

doc. Ing. Stanislav Honus, Ph.D.
Head of Department

VYSOKÁ ŠKOLA BÁŇSKÁ TECHNICKÁ UNIVERZITA
Fakulta strojní
-4-
OSTRAVA

prof. Ing. Ivo Hlavatý, Ph.D.
Dean

Student's affidavit

I declare that I have prepared the whole diploma thesis including appendices independently under the leadership of the diploma thesis supervisor, and I stated all the documents and literature used.

In Ostrava on 20.05.2019

....

Student's signature

I declare that:

- I am aware that Act No. 121/2000 Coll., Act on copyright, rights related to copyright and amending some laws (the Copyright Act), in particular Section 35 (Use of a work in the civil or religious ceremonies or in official events organized by public authorities, in the context of university performance and use of university work) and Section 60 (university work) shall apply to my final Diploma thesis.
- I understand that VŠB – Technical University of Ostrava (hereinafter referred to as "VŠB-TUO") has the right to use this final Diploma thesis non-commercially for its internal use (Section 35 Subsection 3 of the Copyright Act)
- If requested, a copy of this Diploma thesis will be deposited with the thesis supervisor,
- If VŠB-TUO is interested, I will make a licensing agreement with it permitting to use the thesis within the scope of Section 12 Subsection 4 of the Copyright Act,
- I can only use my thesis, or grant a license to use it with the consent of VŠB-TUO, which is authorized in such a case to demand an appropriate contribution to the costs that were incurred by VŠB-TUO to create the thesis (up to the actual amount),
- I understand that - according to Act No. 111/1998 Coll., on higher education institutions and on changes and amendments to other acts (Higher Education Act), as amended - that this Diploma thesis will be available for public before the defense at the thesis supervisor's workplace, and electronically stored and published after the defense at the Central Library of VŠB-TUO, regardless of the outcome of its defense.

In Ostrava on 20.05.2019

....

Signature of the author

Name and surname of the thesis author: Deepak Balaji

Permanent address of the thesis author: Vellore, India

ANNOTATION OF THE DIPLOMA THESIS:

Deepak Balaji, Diploma Thesis - Solar system for a family house for hot water preparation and swimming pool pre-heating. *Ostrava - VŠB –Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Energy Engineering, 2019*, Thesis supervisor: **Ondřej Němček**.

This diploma thesis describes the complete installation and operation of a solar water heating system for a family house in Ostrava. This system provides drinking hot water (DHW) to the three inhabitants living in the house and the overproduction during summer months will be utilized for outdoor swimming pool. The main part of this thesis discusses about suitable components required for complete setup, installation cost and budget of system, and economic and environmental impact it has on the house and comparison of same system operating in India, where the year-round temperature is considerably higher than Czech Republic.

Keywords: Flat-plate collector; Swimming pool; Heat Exchanger.

ANOTACE DIPLOMOVÁ PRÁCE:

Deepak Balaji, diplomová práce – Solární soustava pro rodinný dům pro přípravu teplé vody a přihřívání bazénu. *Ostrava – VŠB – Technická univerzita v Ostravě, Fakulta strojní, Katedra energetiky,2019,* Vedoucí diplomové práce: **Ondřej Němček**

Tato diplomová práce se komplexně věnuje popisu instalace a provozu solárního topného systému pro rodinný dům v Ostravě. Tento systém zahrnuje teplou užitkovou vodu (TUV) pro tři obyvatele domu, přičemž přebytek energie během letních měsíců bude využit pro ohřev vody v bazénu. Hlavní část diplomové práce řeší komponenty potřebné pro provoz soustavy, náklady na její instalaci a také finanční rozpočet, současně je zahrnut i ekonomický a environmentálním vliv na domácnost. V závěrečné části se práce věnuje srovnání provozu stejného systému v Indii, kde je celoroční teplota výrazně vyšší než v České republice.

Klíčová slova: kolektor plochých desek; plavecký bazén; výměník tepla

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

LIST OF VARIABLES

Variable	**Name**	**Unit**
T_a	Ambient temperature	°C
ΔT	Temperature difference	°C
Q_{int}	Average monthly heat	kWhr/m^2
C_p	Specific heat of fluid/water	kJ/kgK
GGh	Average hourly radiation intensity for global horizontal radiation	W/m^2
GGk	Average hourly radiation intensity for global radiation inclined	W/m^2
GDh	Average hourly radiation intensity for diffuse horizontal radiation	W/m^2
GDk	Average hourly radiation intensity for diffuse radiation inclined	W/m^2
GBn	Average hourly radiation intensity for direct normal radiation	W/m^2

INTRODUCTION

Solar energy, the electromagnetic radiation that falls on earth surface as a product of thermonuclear reaction in Sun. This energy source can be utilized for various applications: *generation of electricity, floor-heating and water-hearing* in both commercial and domestic areas. Heating water through thermo solar collector takes place as a principle of space heating method. The design of the building should account for proper insulation for pipes and a storage place to accommodate the system supplies.

This thesis describes about annual production and consumption of solar energy for a house in Ostrava inhabited by 4 persons and bilateral comparison with same system in Indian house under tropical climate.

1. SOLAR ENERGY IN CZECH REPUBLIC

Due to the climatic conditions in the Czech Republic, we cannot rely solely on the solar system. Although the energy production for heating water is sufficient during summer and spring, the same is not applicable for autumn and winter. The solar system achieves the highest efficiency in regions where the total solar radiation is higher and where the air is cleaner, such as South Moravia or Central Bohemia, whereas in case of Ostrava, it is different. This capital city lies in the north-eastern part of Czech Republic in the region of the Moravian-Silesian.

The below table shows the average sunshine hours of each month in city of Ostrava:

Table 1 Sunlight duration in hours [1]

	Average monthly sunshine in hours												**Total**
City	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	(hr./year)
Ostrava	40	57	119	135	191	191	183	193	138	108	49	42	1446

1.1. Why Solar systems should be used

Active functioning solar heating systems are always cost-effective when they are used for most of the year comparing alternatives, even in cold climates where solar resources are not adequate. They are most economical comparing to traditional alternatives like expensive heating fuels, such as electricity, propane, and oil heat. Some states also offer sales tax exemptions, income tax credits or deductions, and property tax exemptions or deductions for solar energy systems in and around Czech Republic for society to take advantage and get benefitted from the solar energy.

There are two basic types of active solar heating systems based on the type of fluid, either ***liquid-based*** or ***air-based*** that is heated in the solar energy collectors. These collectors act as devices in which fluid is heated by the sun. Liquid-based systems heat water(usually for low-cost themal heating) or an ***antifreeze solution*** in a hydronic collector(applied in this project), whereas air-based systems heat air in an air collector.

1.2. Basic data for the use of solar energy

Table 2 Basic data on the energy balance of solar energy use

Total incident energy per horizontal surface per year	950 - 1150 kWh /m^2
Profit from this energy in passive systems	20 - 50% in the heating season
Profit from this energy in active CH systems	30-40% in the heating season*
Profit from this energy in active DHW systems	50 - 80% per year
Profit from this energy in active systems with pool	70 - 90% per season
Profit from this energy in a flat collector for DHW	400 to 550 kWh / m^2 per year
Maximum incident solar energy in summer	8 kWh / m^2 per day
Solar collector efficiency (based on location and usage)	50 - 80%

Table 3 Basics of solar collector orientation.

Optimal orientation of collectors	south - southwest
Suitable collector orientation	south - southeast
Maximum collector power	around 2 pm
Optimal slope for summer operation	about 30 ° from the horizontal
Optimal slope for year-round operation	about 45 °
Optimal slope for winter operation	about 60 ° - 75 °

This above data is collected from tzb – info [2], which shows DHW preparation using solar collector system and collector data required for constructing and operating year round.

2. CLASSIFICATION OF SOLAR COLLECTORS

Solar collectors are classified broadly into two categories considering their interception area:

- Non-concentrating collectors and
- concentrating collectors

2.1. Non-concentrating collector

The collector area, that is, the area where the solar radiation is intercepting is the same as the absorber area, the area where the radiation is absorbed. Solar systems for liquid-heating or air-heating comes under non-concentrating collector type. The most common type of non-concentrating collectors is the flat-plate collector used mainly for water and space heating in commercial buildings and homes where the adequate temperature of less than 100°C is enough.

Flat-plate solar collectors usually have three main components:

- Metal plate(Absorber) - to intercept and absorb solar energy.
- Transparent cover - to allow solar energy to pass through the cover and reduces heat loss from the absorber.
- Insulation layer – to reduce heat loss in the absorber

In the absorber part, metal tubes are attached to solar water heating collectors. To remove heat from the absorber, the absorber tubes are pumped by a heat transfer fluid, which then transfers the heat to the water stored in tank. Solar heating systems for pool water heating during summer usually don't require covers or any insulation for the absorber, and water from swimming pool can be circulated back through the collectors and then to the pool.

2.2. Concentrating collectors

This type of collector is used when the area for intercepting the solar radiation is usually greater, than the absorber area itself. The incident solar radiation focused onto the collector which then concentrates it to an absorber. The collector also supports motion to focus for high degree of absorber concentration. These collectors are usual in powerplants due to their potential to produce high temperature heat outputs.

2.3. Flat plate collector:

The components of a flat plate collector are listed in above topic. Now, brief description of the flat plate collector is discussed:

2.3.1. Absorber:

This part of the collector, Absorber, is responsible for collecting the heat from sunlight and transfer it to heat exchanger by means of a transfer fluid. Since, the heated fluid is carried in high temperatures, absorber is made with materials like steel, copper and Aluminium to transfer without melting or losing heat.

2.3.2. Transport cover:

This part is responsible for reducing heat losses that happen during the absorption and transport of heat. Generally, heat losses occur about 15% to 40% of the total heat transferred depending on the design and materials of the collector system. The heat losses in collector is explained in the figure below:

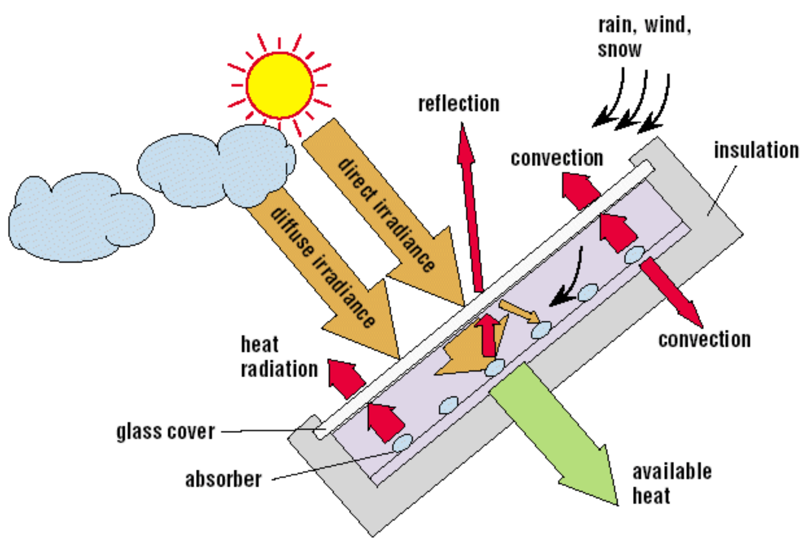


Figure 1 Flat plate collector [3]

Although this transport cover limits the heat losses, some part of loss is still present that is unavoidable due to the air and climatic conditions. As seen in above figure, rain, wind velocity and snow can cause heat losses by one of following ways: Conduction, convection and radiation.

To reduce convection loss, a protective glass can be placed above the absorber. But this glass also reflects the incident sunlight back which can reduce the solar fraction further. Another method is to cover the collector with black coating. This prevents radiation and also increases absorptivity.

2.3.3. Insulation:

Insulation is necessary on the collector circuit to prevent heat loss that occur during transfer of heat. Heat carrying pipes made of copper is used to limit this losses and insulation is provided over the pipe.

For the solar system, three circuits has been designed: Collector circuit, storage circuit and a pool circuit. In collector circuit, transfer fluid transfers the heat. This heat carrying fluid passes through the heat exchanger where the heat is been transferred to storage tank circuit and to the swimming pool circuit. Both these circuits carry water which is why heat exchanger needs to be placed as intermediate.

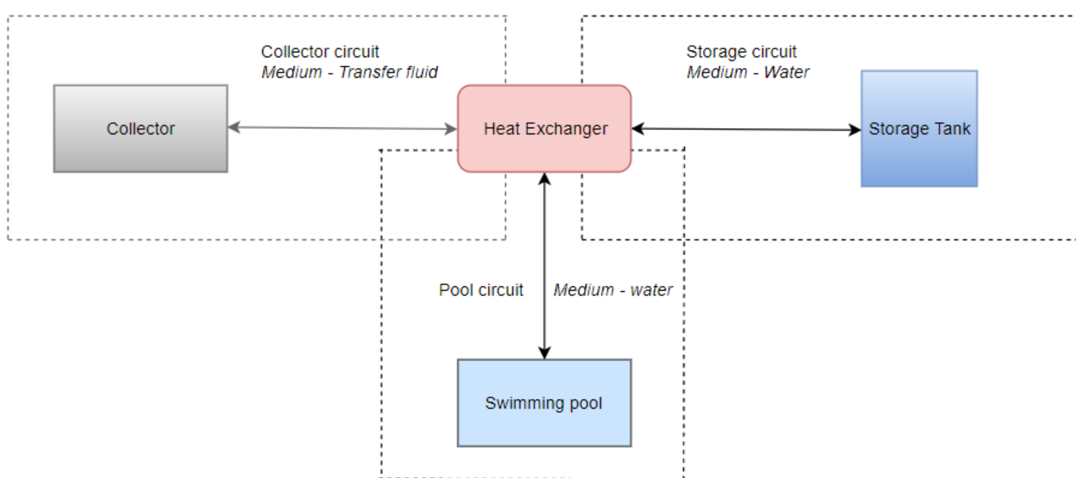


Figure 2 Block Diagram of proposed setup

3. HOUSE DETAILS AND ORIENTATION

The appropriate selection of the house should consider the construction and operation suitability of solar collector installation, regional laws regarding permitted usage of collector in Ostrava region, payback period resulted from economic point of view of the house and conditions of the inhabitants.

The selected house according to above mentioned criteria is a 3-person inhabited house located in Ostrava – Poruba region.

3.1. Description

The geographical location of the study house is in Svinov part of Poruba town, with the following coordinates:

Longitude: **49°49'00.4"N**

Latitude: **18°11'34.2"E**

Location: **Psohlavců 1159/24B, 721 00 Ostrava-Poruba**

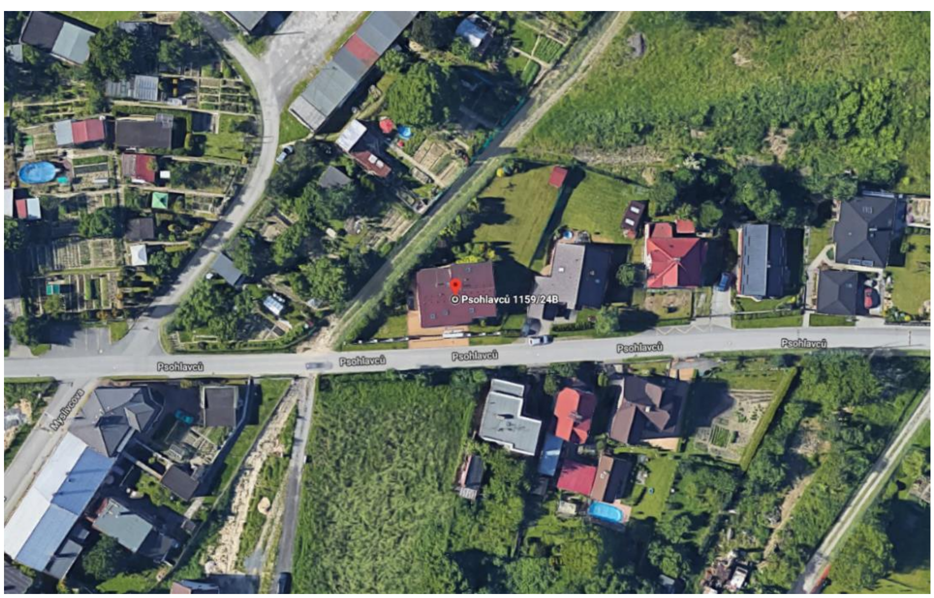


Figure 3 Aerial Map of family house

The study house is in far west to city of Ostrava but lies in its district part and qualifies as a domestic house with support from Ostrava municipality for drinking water, power, waste disposal and other commodities.

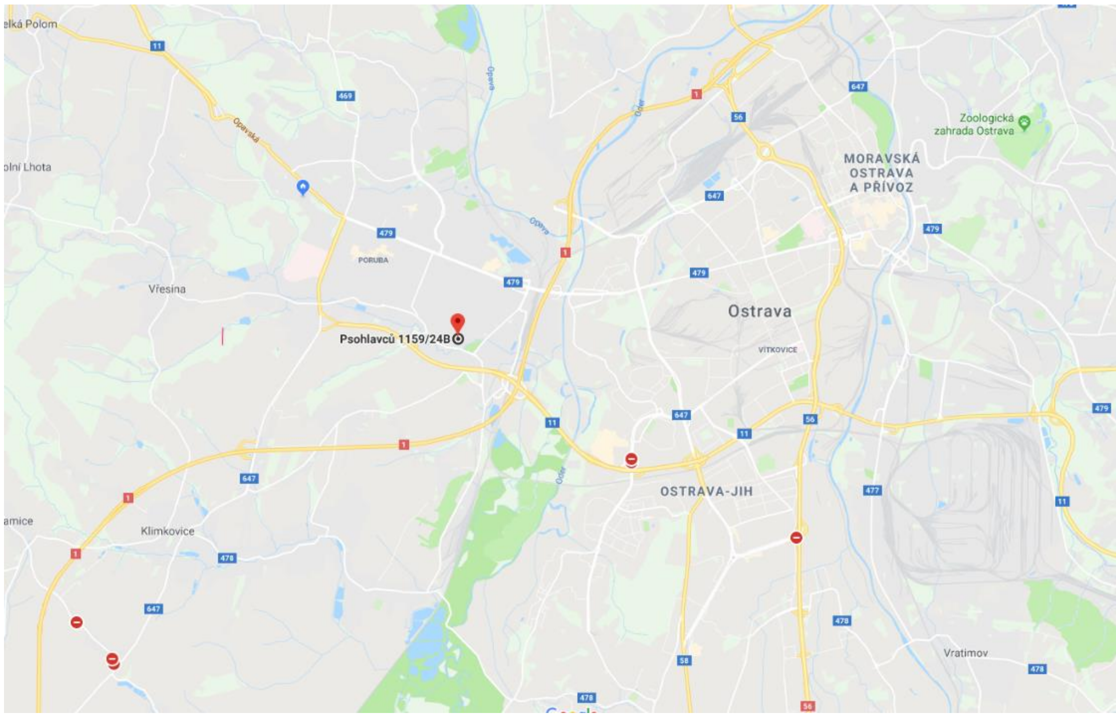


Figure 4 Location of house in Ostrava

This house is situated in outskirts of city and free from tall buildings and other disturbances. This is a 2-storey house with uncovered swimming pool at backyard. The roof **deck inclination** is about **35 degrees** and oriented towards **south** with **azimuth of 0 degree**.

3.2. Energy supply before installation

The energy needed for heating drinking water was obtained from a **Gas boiler system**, a cast-iron boiler which is able to supply hot water to the house throughout the year.

The specifications of the boiler are:

Table 4 Specifications of G36 Boiler

Manufacturer	VIADRUS
Model	Grand G 36
Power Output	20 kW
Efficiency	0.92
Fuel type	Natural Gas

Figure 5 Natural Gas Boiler G36 [4]

The cast-iron sectional boiler drum made of grey cast iron according to:

ČSN 42 2420 - Cast iron 42 2420 with **laminated graphite** as the main part of the boiler.

The boiler construction corresponds to the strength requirements according to:

EN 297 Gas – fired central heating boilers – Type B11 and B11BS fitted with atmospheric burners of nominal heat input not exceeding 70 kW.

The solar heating system replaces this boiler to meet the demand for heating DHW, and during colder months, this boiler acts as auxiliary systems to cover the demand, in case the solar system is not able to meet complete demand.

4. CALCULATIONS

To obtain radiation values for the study house, the entire region of Ostrava – Poruba area is studied. This can be achieved by reported values in government databases or special applications that can provide the radiation levels. For this study, a special application is used, called, Meteonorm, which has a database of stored values for every region in and around Czech Republic. The studied house is situated in physical address: Psohlavců 1159/24B, Poruba and hence the values for Ostrava-Poruba can be selected from last 10 years and can be used for calculation.

4.1. Meteonorm

This application has access to various time series of irradiation and temperature data all around Europe, Middle East, and Asia. The database comprises of reports from 8000 weather stations, geostationary satellites and climatology study. Meteonorm can generate hourly irradiation values based on measured monthly data from various platforms.

For solar energy installations, Meteonorm is very useful application due to:

- Comprehensive database with collection of climatological data from every location of the world.
- Calculate internally within the system and direct display of values.
- Provides data for any type of system: Active, Passive and Photovoltaic applications.
- Standardization tool with simplified interface for better user interaction. [5]

4.2. Procedure for Meteonorm

The following steps demonstrates the fields selected in each window and the inclination, azimuth and temperature factors:

- *Step 1 - Selecting location:*

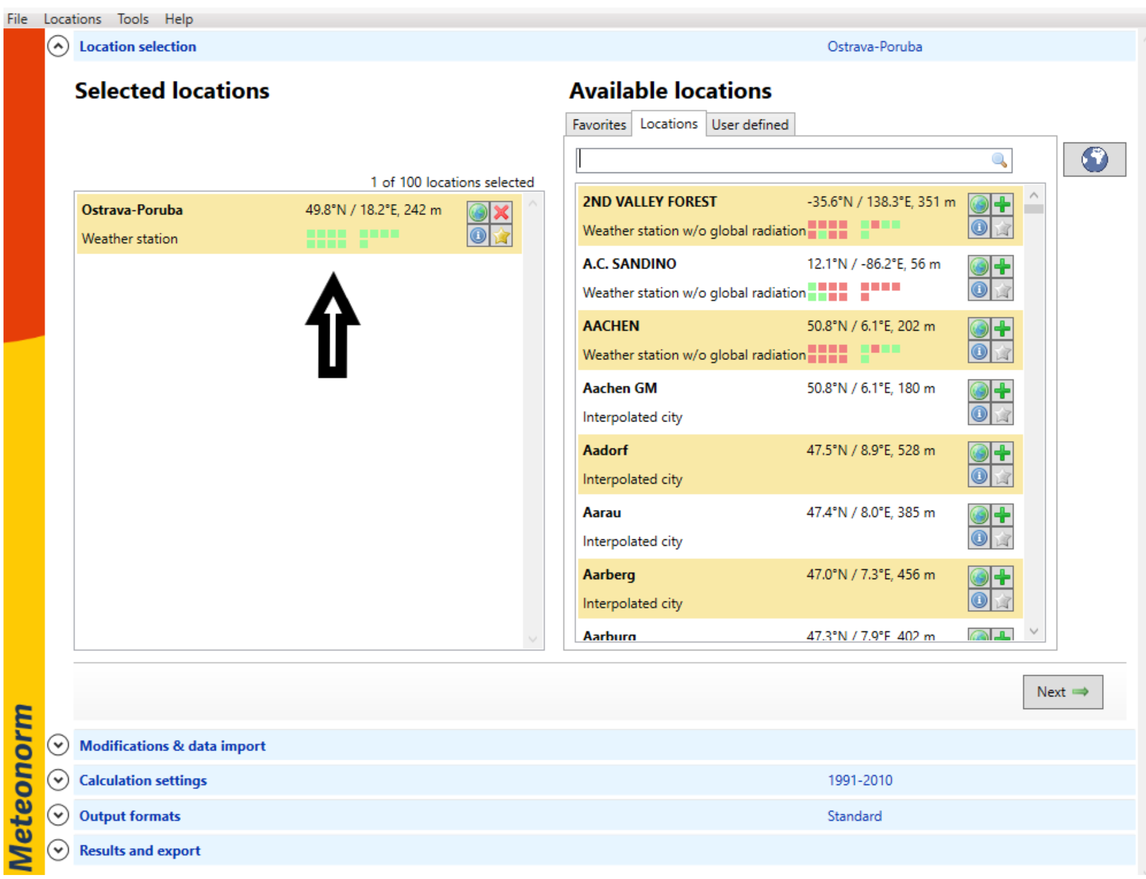


Figure 6 Setting up location - Ostrava Poruba

The initial window displays various cities with their respective country. The selected location field displays the chosen city, in this case, it is Ostrava – Poruba. It is also mentioned the geographical data and altitude to sea level. These values are critical to understand the solar radiation levels at this part of globe.

- *Step 2 – Input known data:*

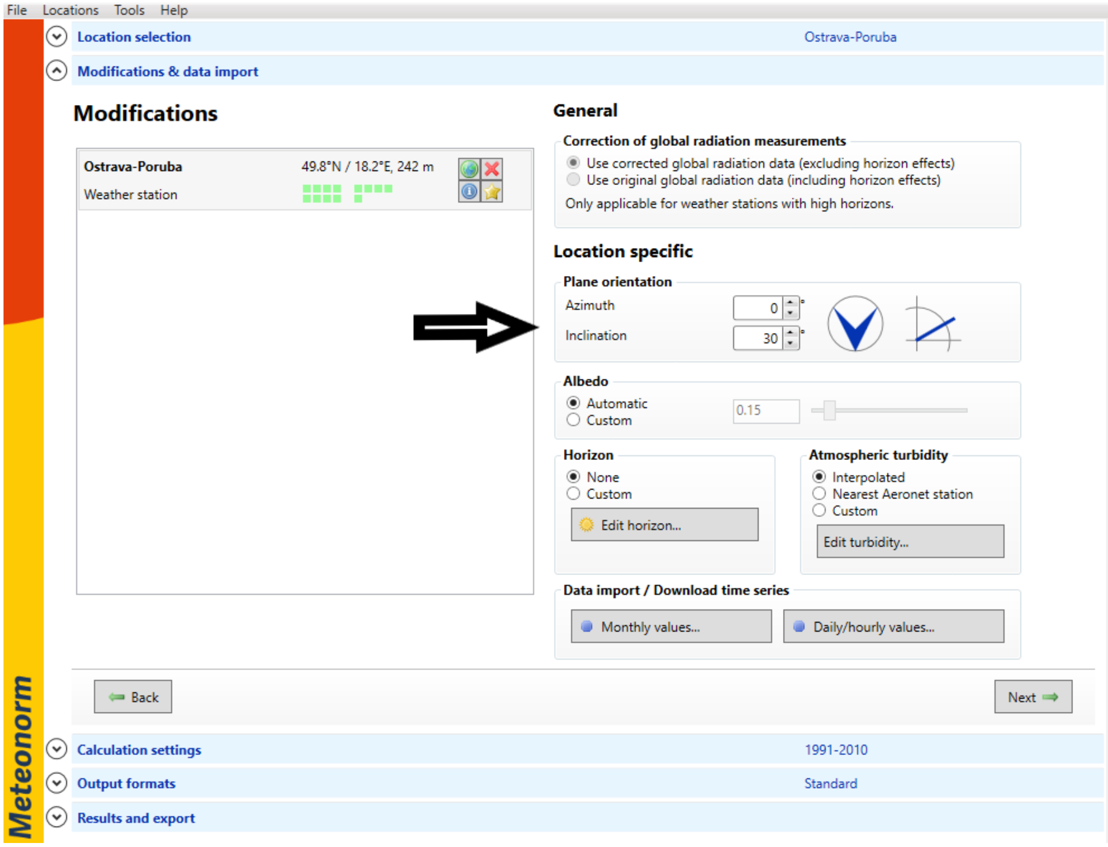


Figure 7 Applying Location modifications

Here, the values for Azimuth angles and Orientation of the roof is entered and other input values, if required are entered in their respective fields. For this study, Azimuth remains same (0 degree) while inclinations vary (30, 40, 45, 55 degrees).

- *Step 3 – Target period:*

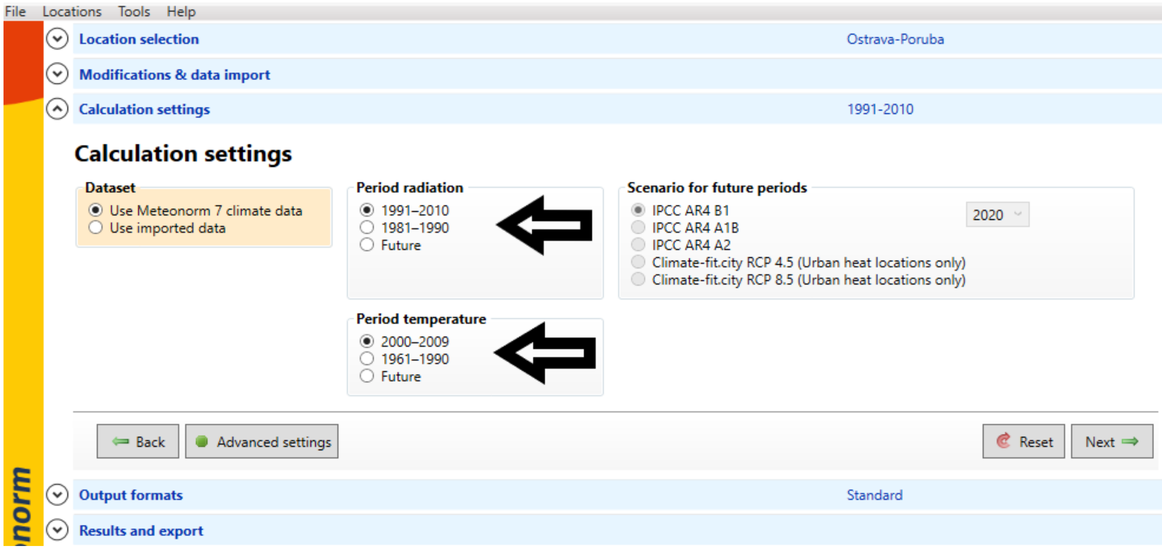


Figure 8 Selection of time period

Here, the required timeframe for obtaining the radiation and temperature values are chosen. The radiation levels can be obtained for last 20 years between (1991 - 2010) and temperature between (2000 - 09). There is also possibility to obtain values for future years with help of Meteonorm forecasting feature.

- *Step 4 – Output formats:*

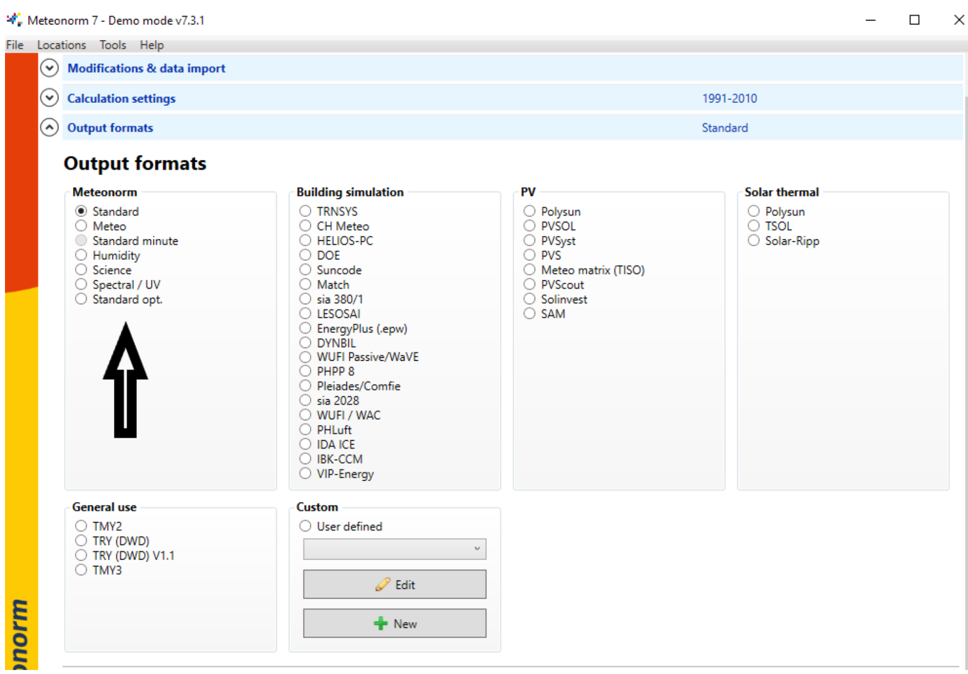


Figure 9 Standards selection for output

In this window, the desired output format can be chosen. For example, in case of simulation option **TRNSYS** – the following values can be obtained:

G_Bh, G_Dh, Ta, FF, RH

For this study, **Standard Meteonorm values** are sufficient since it yields all the required values needed.

- *Step 5 – Result generation:*

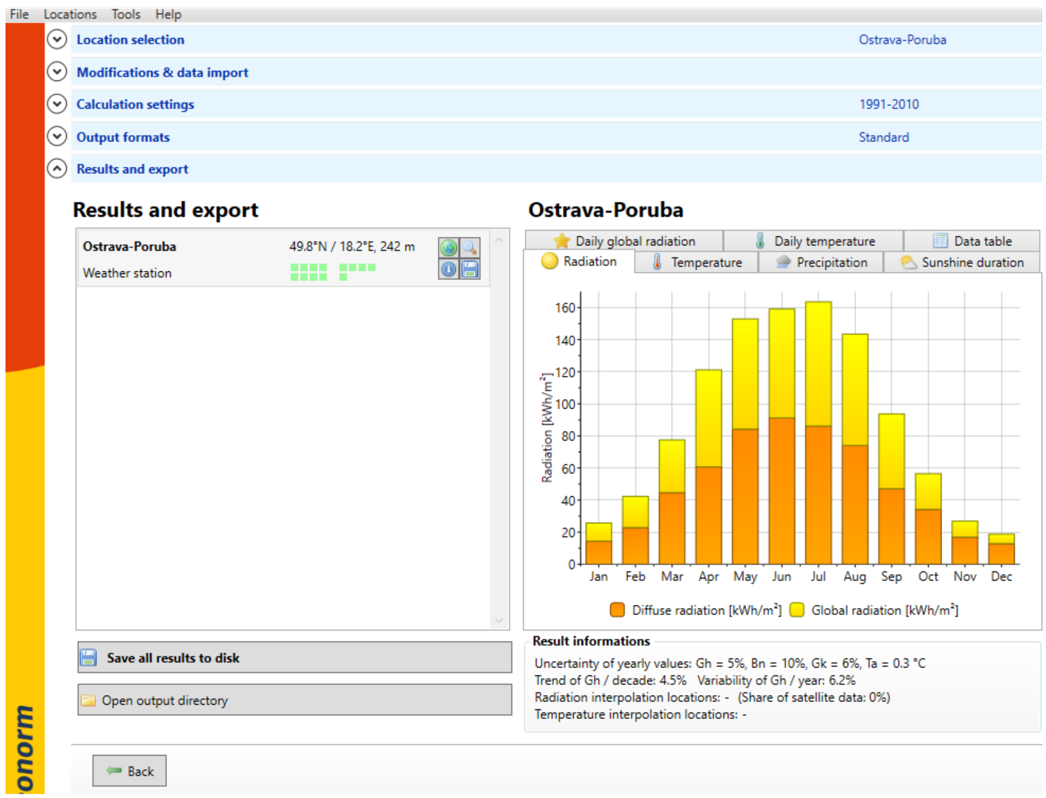


Figure 10 Output results extraction

The final step involves extraction of final output values corresponding to hourly, daily and monthly calculated values of global radiation, diffuse radiation, direct and inclined radiation and air temperatures.

Ostrava-Poruba

Radiation | Temperature | Precipitation | Sunshine duration

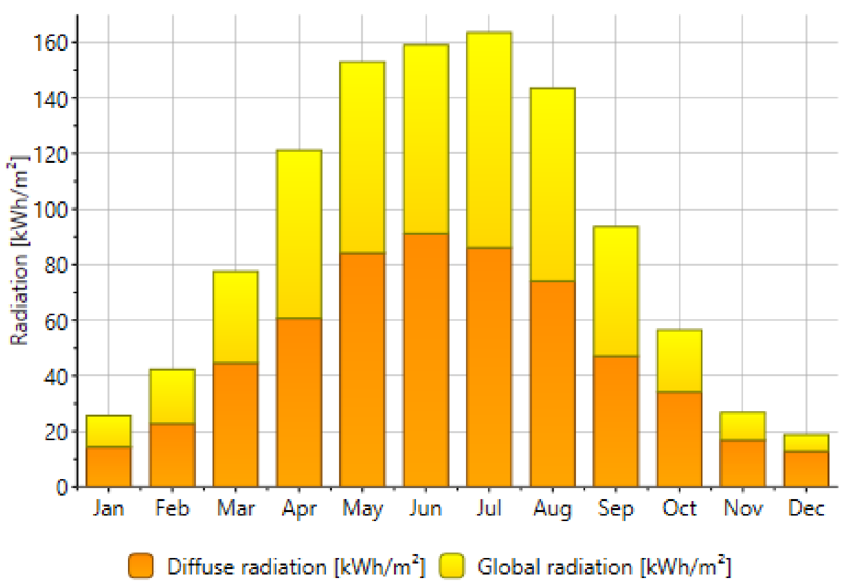
Daily global radiation | Daily temperature | Data table

	Gh kWh/m²	Gk kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	26	47	14	45	-1.3	-3.9	4.5
February	42	65	23	55	0.4	-2.8	4
March	78	98	45	74	3.5	-0.6	3.9
April	121	140	61	110	9.5	3.3	3
May	153	158	84	112	14.5	8.8	2.9
June	159	157	91	109	17.5	11.8	2.7
July	164	164	86	126	19.3	13.5	2.8
August	144	156	74	120	18.9	13.4	2.5
September	94	112	47	92	13.9	9.3	2.7
October	56	77	34	55	9.8	6.2	3.3
November	27	43	17	36	5.2	2.3	3.8
December	19	32	13	26	-0.1	-2.4	4.3
Year	1079	1247	589	961	9.3	4.9	3.4

Result informations

Uncertainty of yearly values: Gh = 5%, Bn = 10%, Gk = 6%, Ta = 0.3 °C
Trend of Gh / decade: 4.5%   Variability of Gh / year: 6.2%
Radiation interpolation locations: -   (Share of satellite data: 0%)
Temperature interpolation locations: -

Figure 11 Temperature and Radiation data for each month



Graph 1 Diffuse and Global Radiation [5]

4.3. Cold water input

Table 5 Average monthly cold water temperature

Average temperature of cold water – OSTRAVA	
January	8.25
February	7.68
March	8.11
April	9.44
May	11.35
June	13.31
July	14.80
August	15.41
September	14.97
October	13.60
November	11.69
December	9.73

The above values are Average supply temperature of cold water obtained from data collected from *Meteonorm* [5] and advised by *Energy department of Technical University of Ostrava*. These are combined values calculated from hourly data of each days of month along with irradiation factors.

The cold water supply from the regional city of Ostrava, varies in temperature due to resulting weather and humidity factors of varying months from January through December. The cold water during winter ranges between 6 – 10° C while during summer, the water can go as high as 17° C.

5. CALCULATION OF DEMAND

The study house is been inhabited by **3 persons** who live there throughout the year, for 365 days. The data from municipality reports that average consumption of water is around 60 liters per person per day in rural areas and around 80 liters in urban areas. So, for this calculation, **average daily DHW consumption** of **60 liters/person** per day is chosen.

This means that the system needs to meet the daily demand of about **180 liters per day**. Production can be higher than 180 L, but it should be never less.

The suitable **temperature of hot water** that should be obtained as output should be **60°C**, which is fixed value that should be obtained year round from the solar installation.

To calculate the demand, the following equation is used which should be determined for individual months due to varying cold temperatures and number of days in month.

$$\boldsymbol{Demand} = \frac{Daily\ consumption * Cp * \Delta T * Number\ of\ days}{3600}$$

Where:

- *Cp*: Specific heat of water.
- *ΔT*: Temperature difference between water supply and consumption.
- The factor “*3600*” is used as conversion factor to obtain result from kJ to kWhr.

Demand for April month with 30 days is:

$$\mathbf{Demand} = \frac{180 * 4.18 * 50.5 * 30}{3600}$$

Demand for APRIL**= 316 kWhr**

This below table shows the monthly demand calculated based on temperature difference and number of days:

Table 6 Calculation of Demand

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of Days											
31	28	31	30	31	30	31	31	30	31	30	31
Cold water temperature											
8.25	7.68	8.11	9.44	11.3	13.31	14.8	15.4	14.9	13.6	11.6	9.73
Temperature difference *ΔT [°C]*											
51.7	52.32	51.8	50.5	48.6	46.6	45.2	44.5	45.0	46.4	48.3	50.2
Demand per month [kWhr]											
335	306	336	316	315	292	292	288	282	300	302	325

The total annual demand of DHW consumption is accounted to be **3695.88 kWhr.** This demand is only theoretical value and during operation, in practical, there will be heat loss that has to be considered which accounts for 10% of overall demand. This heat loss depends on the construction of the building, the total area of site and other parameters.

5.1. Solar collector selection

The selection of collector is the most important part of this project as this plays a major role in the solar system efficiency and operation conditions. Since, the annual demand of consumption is known, the collector can be selected that can supply this demand for given cold water temperature.

The two main collector types that are usual for domestic water heating systems are:

- Flat plate collectors and
- Vacuum tube collectors.

The advantages of using Vacuum tube collectors is the high temperature output can be obtained, since the vacuum inside acts as good conduction of heat. However, it has a major disadvantage that puts flat plate collector to advantage. The design and installation of vacuum tube collectors are complex and costs more comparing to flat plate collectors.

By comparing these two collectors, even though vacuum tube collectors produce high temperature water outlet, the cost efficiency has major drawback as flat plate collector has minimal difference in output temperature but much better cost efficiency.

A simple comparison of two collectors are given in below graph illustrating their efficiency over thermal efficiency.

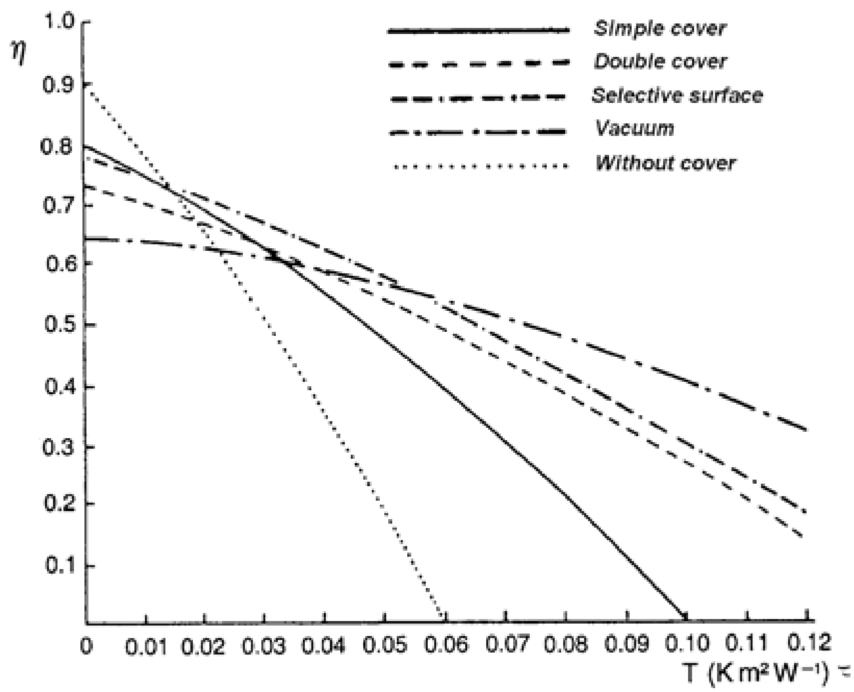


Figure 12 Efficiency curve for different collectors [3]

From the graph, it is clear that flat plate collectors are ideal for this study as efficiency improvement of collector is not part of this project. Flat plate collectors have simple design and easy to assemble and install, which also results in minimal maintenance and service costs.

5.2. Proposed model

The selected model of collector should satisfy conditions of flat plate type, and also cover the demand with minimal number of collectors. From the solar collector databases available from SPF: Institut fur Solartechnik, under flat plate collector field, suitable collector is chosen.

In this case, it is **Hassler Omegasol S**, a flat plate collector model manufactured by Hassler Alternative Energie GmbH [6].

The general and technical information of this collector is given below:

Table 7 Technical data of Omegasol S collector

Collector Data	
Model	Omegasol S
Type	Flat-plate collector
Manufacturer	Hassler Alternative Energie GmbH
Dimensions	
Total length	1.23 m
Total width	2.48 m
Aperture area	2.762 m²
Efficiency coefficients	
Conversion factor (η_0)	0.814
Loss coefficient a1	3.99 W/(m²K)
Loss coefficient a2	0.0092 W/(m²K²)
Technical Data	
Minimum volume flow rate	42 L/hr.
Recommended volume flow rate	120 L/hr.
Maximum volume flow rate	150 L/hr.
Maximum operating pressure	6 bars
Maximum operating temperature	120 °C

Below figure shows the different area of the collector according to its specifications:

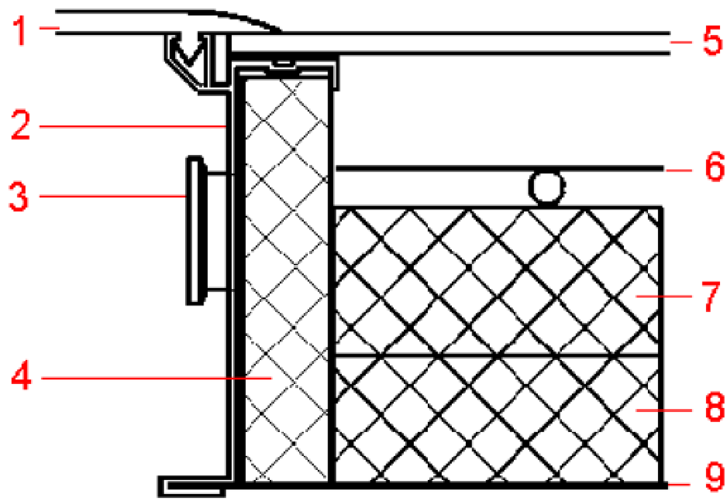


Figure 13 Schematic diagram of collector [6]

Where:

- 1 – Cover rail
- 2 – Frame
- 3 – Hydraulic connection
- 4,7,8 – Thermal insulation
- 5 – Glazing
- 6 – Absorber
- 9 –Backside

Table 8 Areas of Collector panel

Reference Area	Aperture	Absorber	Gross
η_0	0.796	0.814	0.721
a_1 [W/m^{2}k]	3.90	3.99	3.53
a_2 [W/m^{2}k]	0.0090	0.0092	0.0081

5.3. Efficiency Curve

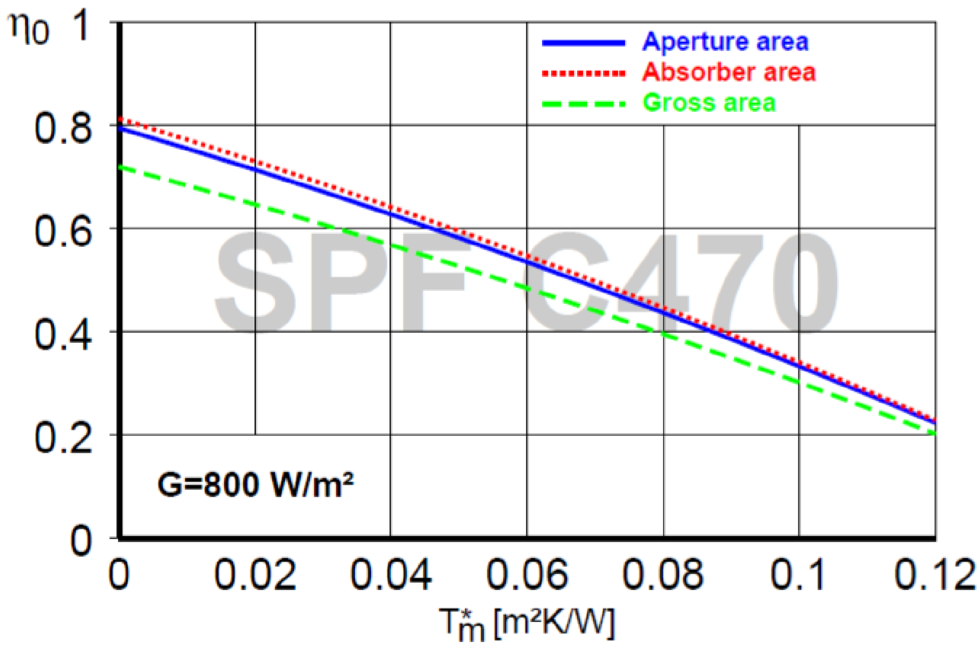


Figure 14 Efficiency curve of Omegasol S [7]

5.4. Angle Factors

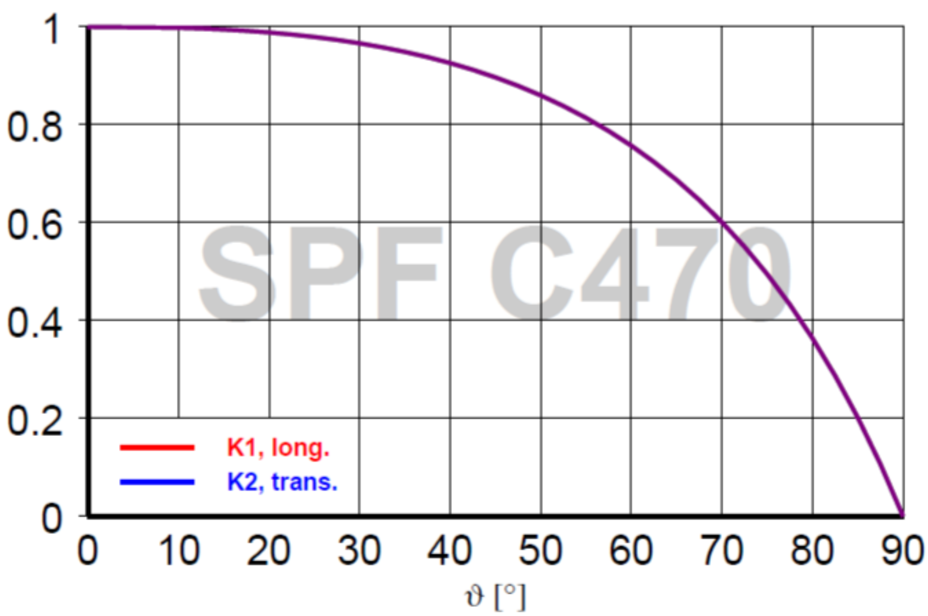


Figure 15 Angle factors for Omegasol S [7]

After the selection of collector, the next step is to determine proper inclination of the collector panel in order to obtain maximum energy from solar radiation. Its already determined that the roof is facing south and inclined at about 35 degrees.

6. STUDY OF INCLINATIONS

To choose the suitable inclination angle, first various angles are considered and studied for solar fraction where the maximum yield is obtained. This solar fraction is defined as percentage of solar energy consumption by the solar system. The study angles considered are:

- Inclination of 30°
- Inclination of 40°
- Inclination of 45°
- Inclination of 55°

The data used to derive solar fraction is obtained from Meteonorm program and SPF: Institut fur solartechnik where the necessary area of collector is calculated that should be necessary to meet the demand and comparing with actual collector with given aperture area. This cumulative data constructs a well calculated results that can be compared for each inclination.

Figure 16 Collector model from Hassler energie [6]

6.1. Solar fraction

To determine the solar fraction for each month, first the total demand of house, overall productivity of the solar collector, Useful gain and overproduction needs to be calculated.

6.1.1. Total Demand

For this calculation, below data from January month is taken as example. Listing known values:

- Number of inhabitants – 3
- Average daily water consumption – 60 Liters
- Desired output temperature - 60° C
- Average monthly heat Q_{int}(January) – 24.95 kWhr/m^2

Demand for January,

$$Demand = \frac{Daily\ consumption * Cp * \Delta T * Number\ of\ days * No.of\ persons}{3600}$$

$$\text{Demand} = \frac{60 * 4.18 * 51.75 * 31 * 3}{3600} = 335.3\ kWhr.$$

6.1.2. Heat loss

Heat losses due to convection and radiation is given below:

$$Demand\ including\ loss\ = \ Total\ Demand * Heat\ loss(15\%)$$

Final demand = 335.3 * 0.15 = 385.6 kWhr

Hence, suitable heating system must be designed that is capable of meeting this final demand. Although, choosing collector specifications based on this calculated demand is possible, it is not economical. This is where the required area of panel is important.

6.1.3. Required Area

To cover this total demand, the needed collector area is given by:

$$Necessary\ Area = \frac{Final\ Demand}{Qint} = \frac{385.6}{24.95} = 15.45\ m^2$$

This necessary area obtained is only for January month and this value tends to change due to the change in Average monthly heat and the demand. So, for proposal of this system, it is decided to take **MARCH** as reference month. For April, the necessary area needed to cover demand is about **8.14 m²**.

This system is unable to meet the total demand during January with this proposed area of 8.14 m^2. But this can be substituted by Auxiliary system.

6.1.4. Production output

Omegasol S panel has absorber area of 2.7 m^2 and selection of three panels add up to 8.1 m^2.

With this area, collector can produce:

$$Production\ output = Average\ monthly\ heat(Q) * Proposed\ Area$$

$$= 24.95 * 8.1 = 202.1\ kWhr$$

But the required demand is 385.6 kWhr for January and this uncovered demand of 183.5 kWhr will be supplied by Natural Gas Boiler.

6.1.5. Overproduction

In case of summer months, the production is more than the required demand. For example, during June, Average monthly heat is about 76.39 kWhr/m^2

$$Production\ output = 76.39 * 8.1 = 618\ kWhr$$

Required demand for June is 336.8 kWhr and the remaining production of 282.12 kWhr is supplied for Swimming pool.

6.1.6. Solar Fraction

Calculation of solar fraction with the above obtained results:

$$Solar\ Fraction = \frac{Production\ Output}{Final\ Demand} * 100$$

$$Solar\ fraction(\%) = \frac{202.1}{385.6} * 100 = 52\%$$

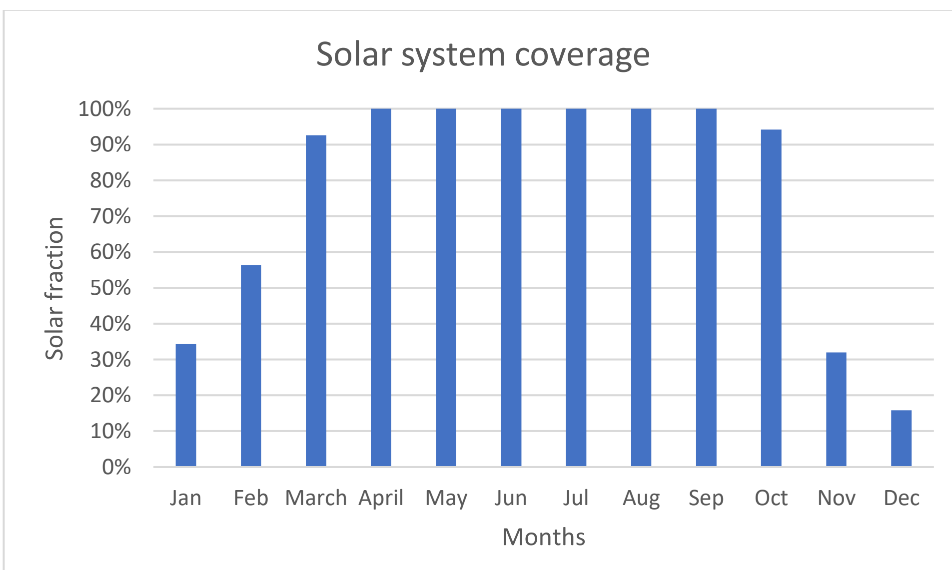
In case of Summer months, this solar collector reaches as maximum as 215% indicating the over production of heating.

6.2. Results of solar fraction

- *Inclination of 30°*

Table 9 Solar fraction for inclination *30°*

Months	Solar fraction
January	34%
February	56%
March	93%
April	100%
May	100%
June	100%
July	100%
August	100%
September	100%
October	94%
November	32%
December	16%
Total	**76%**

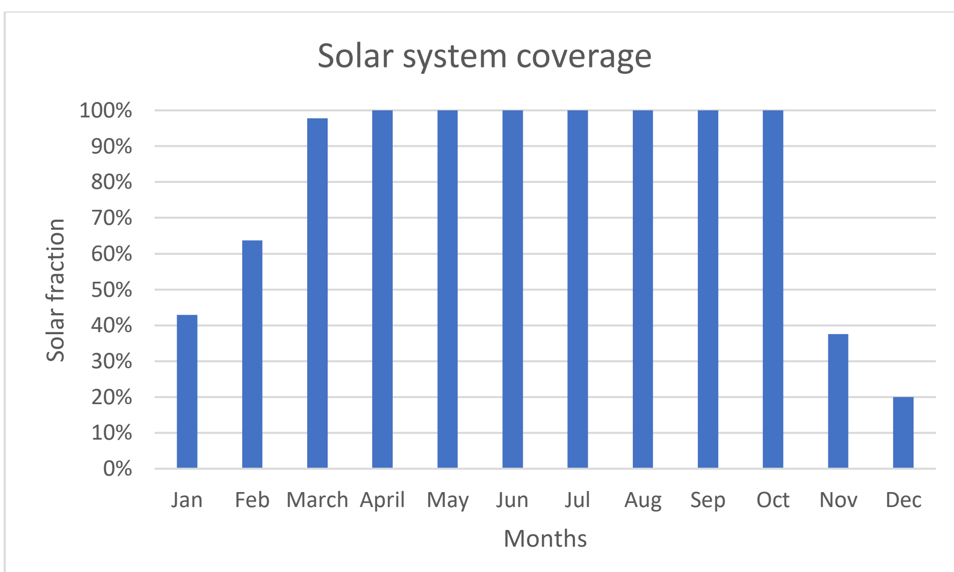


Graph 2 Graphical representation of Solar fraction for each month

- *Inclination of 40°*

Table 10 Solar fraction for inclination 40°

Months	**Solar fraction**
January	43%
February	64%
March	98%
April	100%
May	100%
June	100%
July	100%
August	100%
September	100%
October	100%
November	38%
December	20%
Total	**79%**

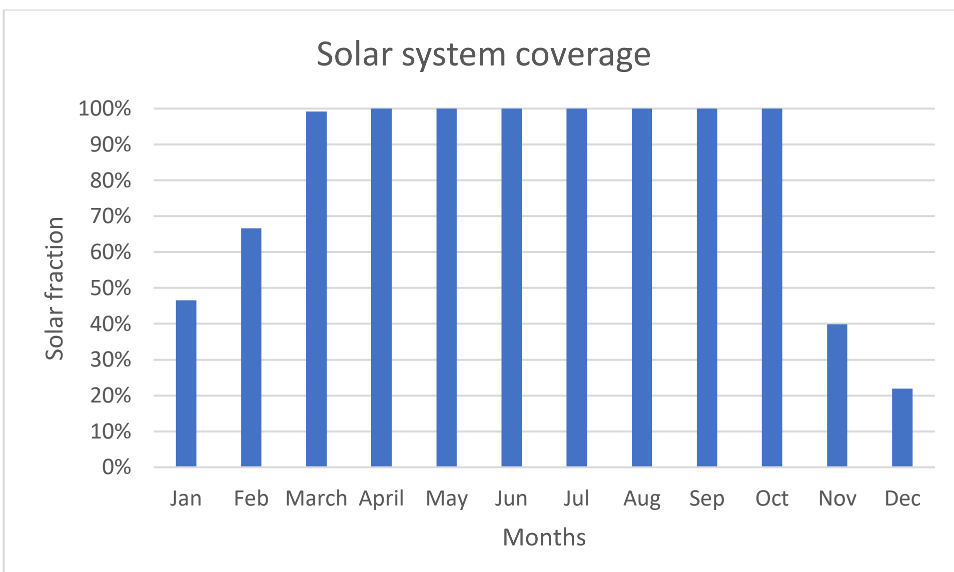


Graph 3 Graphical representation of Solar fraction for each month

- *Inclination of 45°*

Table 11 Solar fraction for inclination 45°

Months	**Solar fraction**
January	47%
February	67%
March	99%
April	100%
May	100%
June	100%
July	100%
August	100%
September	100%
October	100%
November	40%
December	22%
Total	**80%**

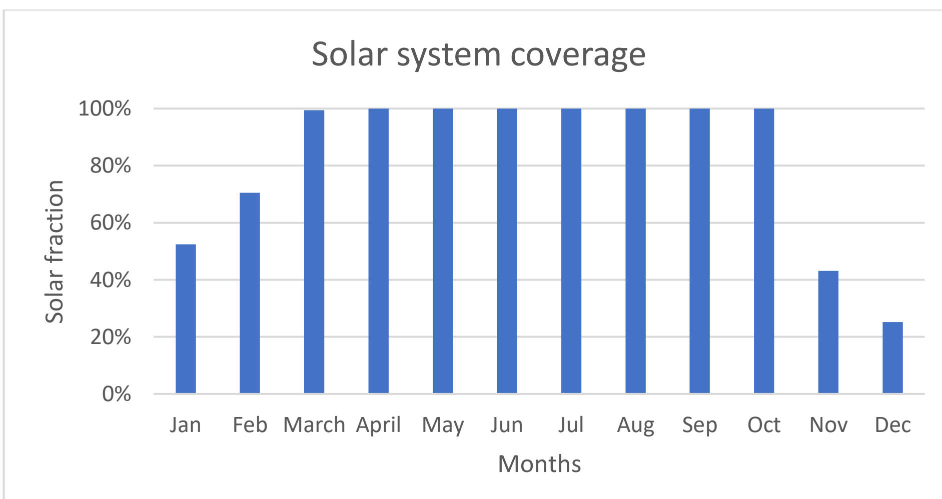


Graph 4 Graphical representation of Solar fraction for each month

- *Inclination of 55°*

Table 12 Solar fraction for inclination 55°

Months	Solar fraction
January	52%
February	71%
March	99%
April	100%
May	100%
June	100%
July	100%
August	100%
September	100%
October	100%
November	43%
December	25%
Total	**82%**



Graph 5 Graphical representation of Solar fraction for each month

6.3. Study results

From the calculation of solar fraction for individual inclinations, its visible that maximum yield is obtained for **inclination angle 55°.**

Solar fraction is 100% during summer months (April through October) which means that the solar collector can provide enough supply hot water to meet the demand during these months. During colder months, the solar fraction is lower indicating that auxiliary system should be used to cover the remaining demand. The **total solar fraction** for annual calculation accounts to be **82%.**

Below chart explains the relation of solar fraction percentage with productivity of the solar system:

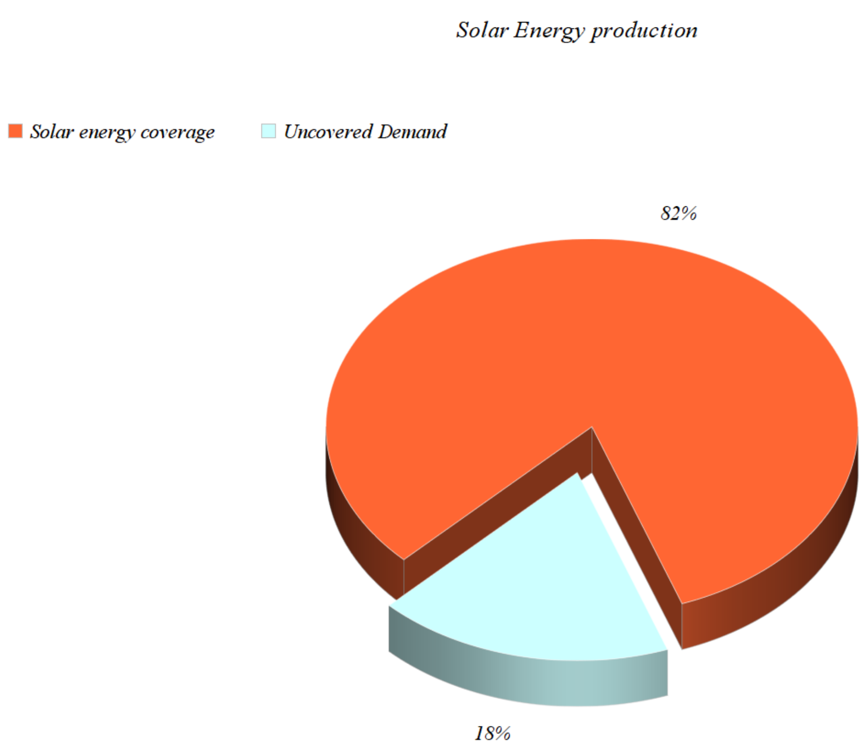


Figure 17 Solar fraction for proposed system

This uncovered demand can be solved by installation of auxiliary system, which in this case, is a Gas boiler. This gas boiler should cover remaining 18% of the demand during colder months.

From the above study, these parameters are obtained:

- Collector type and model
- Inclination angle of the collector
- Number of collectors needed
- Solar fraction of the collector

6.4. Collector arrangements

The next step is to determine which type of connection pattern is suitable for this Collectors. First, the basics of collector data used for construction is known:

1. Area of collectors = **2.762 m^2**
2. Number of collectors = **3**
3. Total catchment area = (3*2.762) = **8.1 m^2**
4. Collector loss coefficients:
    - a_1 = **3.99 W/m^2k**
    - a_2 = **0.0092 W/m^2k**
5. Inclination = **55°**
6. Orientation of roof = **0°**

These three collectors need to be arranged in a pattern, so that the system produces maximum heat output, but at the same time, should have better mass flow and minimal losses.

Various patterns that can be arranged are classified below:

- Series pattern
- Parallel pattern
- Series – parallel pattern

6.4.1. Series connection type

This type of arrangement is suitable for high temperature outputs and constant flow throughout the collector. But the disadvantage is that the efficiency of the collector is very minimal. This also brings another restriction of allowing only 3 collectors in this arrangement. In case of DHW preparation, the collector count is only 2. This puts this arrangement least favorable for this project.

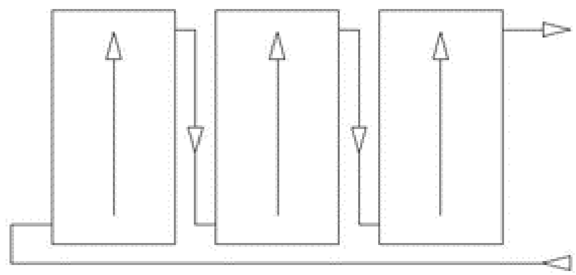


Figure 18 Serious connection [8]

6.4.2. Parallel connection type

Parallel arrangement guarantees high mass flow comparing to series arrangement and able to support multiple number of collector connections. The main disadvantage for this arrangement is that, although it supports multiple number of collector connections, the efficiency will tend to affect when there are more than 8 collectors connected in parallel. This is because of non-uniform flow inside the collector.

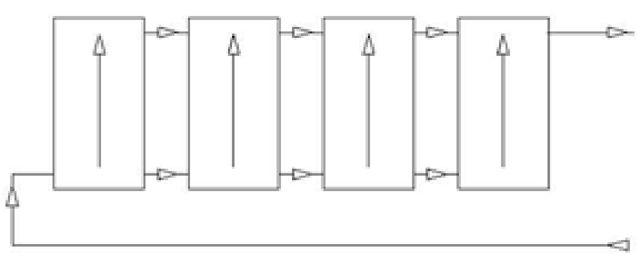


Figure 19 Parallel connection [8]

6.4.3. Series – Parallel arrangement type

This is hybrid arrangement that combines both series and parallel arrangements for better configuration of the system.

Final consideration is given to parallel arrangement as it can allocate 3 collectors and doesn't affect efficiency like in series arrangement. After the collectors are arranged in parallel arrangement, the unit is connected to valves at both ends. These valves support as **balancing valves**, since the flow needs to be uniform and balanced throughout the circuit with minimal heat loss from the system.

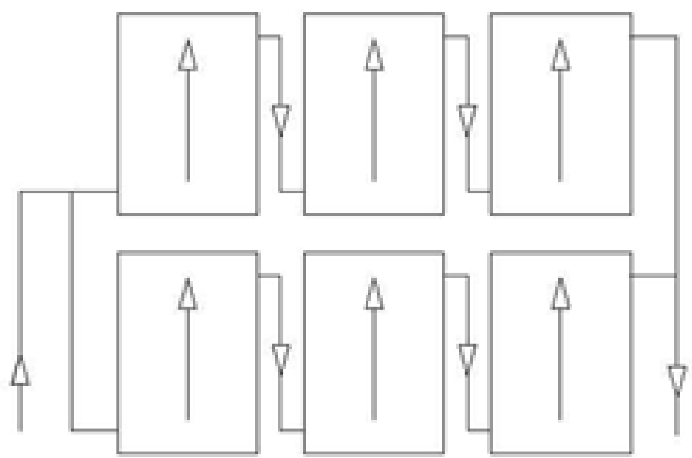


Figure 20 Series - Parallel connection [8]

6.5. Mounting of Collectors

The collector unit must be mounted on the roof and should be permanently fixed. Since this study house has sloped roof of **inclination 35°,** a support frame is required to satisfy the required incident angle of 55°. This support frame should provide additional **angle support of 20°** and also acts as a support unit that fixes the collector unit on the roof by means of steel profiles.

This support frame also acts as passage of heat transferring fluid between collectors connected adjacent to each other.

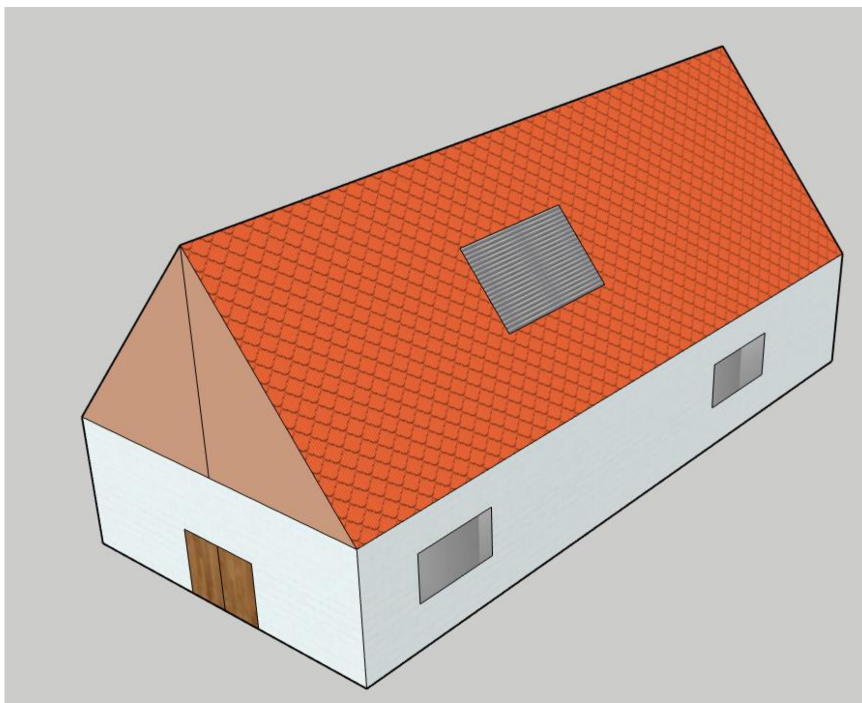


Figure 21 Collector placement designed from SketchUp software

As visible from the model above, the collector is placed in the roof side facing south at an angle of 55° for maximum heat incident onto the collector. Since the roof is facing directly towards south, with azimuth angle of 0° (meaning not towards southeast or southwest), the support frame need not to change orientation angle of the collector. This collector unit is connected to other system parts such as Storage tank, monitoring meters and other hydraulic units, which will be placed in ground floor storage room directly below the unit.

6.6. Heat transfer fluid

Heat-transferring fluids are responsible for carrying heat from solar collector to heat exchanger. This fluid passes through collector and absorbs heat radiation from sunlight. Based on collector types and consumer needs, selection criteria for fluids may vary as follows:

6.6.1. Thermal capacity

This is the most important factor for any heat conducting fluid. It is the ability of the fluid to store heat for a specific period of time without losses or transfer to other mediums by conduction, convection or radiation.

6.6.2. Freezing and Boiling point

Boiling point refers to a point at which the fluid starts to boil. This can cause serious fluid loss in the collector due to evaporation and also release of harmful gases (CFC in case of refrigerant fluids).

Freezing point is that point when the liquid, under colder climates, begins to freeze and turns to solid state. This is also not viable to this collector system since the fluid has to transfer the heat. This both factors make water unsuitable for this application because of its boiling and freezing point.

6.6.3. Flash point

Since the application of this fluid is to absorb heat and store it, this changes the fluid nature between liquid and vapor. When this vapor is intact with air, it gets ignited.

6.6.4. Viscosity of fluid

Viscosity refers to resistance of the fluid during flow. Every fluid has a positive viscosity, and high viscosity fluids tends to be more solid and low viscosity fluids are more liquid type. Everyday observations of these two fluids: Water and Oil, with oil having high viscosity than water.

6.6.5. Coefficient of Expansion

When there is change in temperature, materials and fluids tends to expand, i.e., change in physical length (for materials) and volume (for fluids).

6.7. Selection of fluid

Considering these above factors, chosen fluid is **Sentinel R100 Solar thermal fluid** [9] after careful consideration of its applications and properties. The main aspect of this fluid is its resistance against corrosion by buffering pH values of the fluid.

Table 13 Physical and chemical properties

Properties	
Physical state	Liquid
Appearance	Aqueous soln.
Odor	Odorless
Color	Blue
pH value	8.5
Boiling point	104°C
Density	1.04 gm/cm^3
Viscosity	5 mm^2/sec.

Figure 22 Transfer fluid - Glycol [9]

This is a **propylene glycol** mixture consisting of two major composition: *Propane-1,2-diol and Potassium hydroxide*. This transfer fluid satisfies the freeze point criteria due to its freeze protection circuit upto -25°C. Before application of the fluid, the collector system should be cleaned and flushed with R200 system cleaner and air inside the system should be removed by Sentinel solarflush, both provided by manufacturer.

6.8. Storage tank

Solar collector can't satisfy demand every 24hrs, due to average solar incident of 8 – 10hrs a day in summer and 4 – 5hrs a day in winter. So, in order to supply continuous flow of DHW, an **accumulation tank** needs to be placed at the end side of the collector.

This accumulation tank collects the hot water from the collector, stores it and can be retrieved later when the demand occurs. Since the water stored in the tank needs to be hot throughout the time, with no heat loss to the surrounding, various possibilities are considered in choosing an accumulation tank comparing with normal storage tanks.

First possibility is choosing appropriate material for the tank with proper insulation. Usually, these tanks are constructed in steel, Aluminium or stainless steel materials. Second possibility is to achieve a phenomenon called **Stratification**.

Stratification is a process of layering different mediums over one another. In this case, the hot water that was fed into the accumulator by the collector needs to be remained hot until it is drawn out for usage. For this, the tank should be designed in a way, that the total height of the cylinder from base should be more than the diameter, making it a horizontal cylinder [10].

This horizontal tank stores hot water on top of cold water in the cylinder causing stratification. When the hot water is needed, the water on top is drawn out while cold water is drawn inside from bottom of the cylinder which is heated by the coil connected to solar collector.

During summer months, the hot water needed for demand is achieved only by the solar collector and in sometime of months, there is result of overproduction too. But in colder months, this is not the case. An auxiliary system, that is, the gas boiler should be connected as bypass coil to the bottom of the cylinder to pre-heat the cold water.

This combination of using both the systems (dual coil) has also advantages when it comes to larger demand. When large amount of hot water is needed, like full capacity of tank, then both systems are operational to provide the required capacity and to keep the storage tank ready with hot water for backup. This dual coil setup increases rate of stratification and efficiency of both these systems.

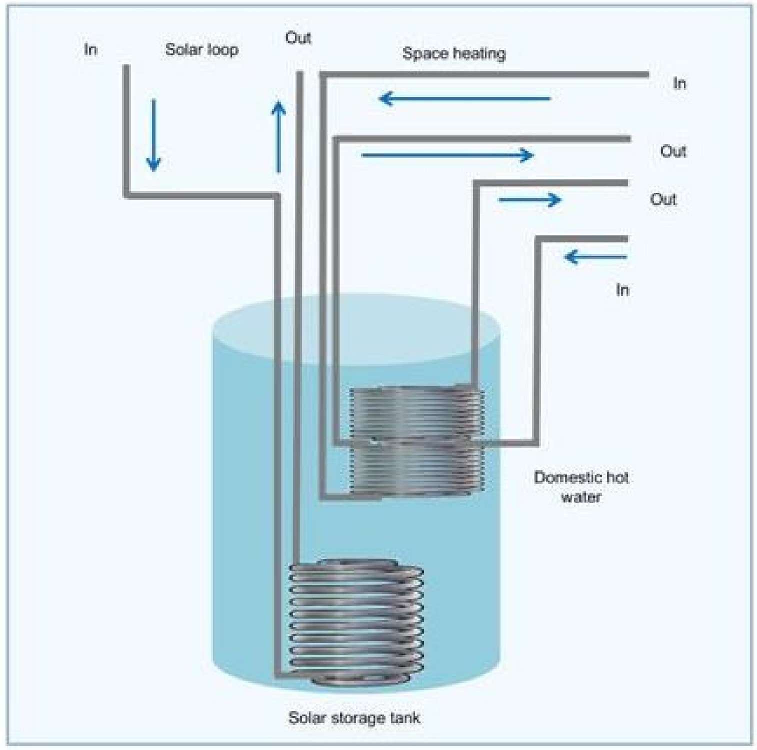


Figure 23 Storage tank for DHW supply [10]

From the above figure, it is known that the coil connecting solar collector to the tank is placed at the bottom of the cylinder while the coil from auxiliary system is one step above. The outlet for hot water is placed at the top of the cylinder and the water at this level is being filled from bottom heated water. In usual solar systems for heating water, the storage tanks are counted for **total number of two**. This is to supply the required demand at any cost. When the accumulation tank is full, the hot water is transferred to the secondary tank for immediate use. This kind of setup is followed when only one system is connected to storage tanks, i.e., when only solar collector is able to provide heating water and that too, during hotter months.

But in this case, since there exist **two systems for sequential heating**, the demand is met at all times independent of time period and weather. But, during hotter months, the solar collector is able to provide more than 100% of the demand and this overproduction should be used economically considering the cost and efficiency of the system

6.9. Designing storage tank

To choose a suitable storage tank, its capacity has to be determined. This can be done by the known values of Daily consumption of water by the inhabitants for a specified amount of time.

Usually, the tank should be able to accommodate at least **two times** the daily demand. In case of more than 10 inhabitants, the number will be three times or more than daily demand in order to meet any unexpected situations.

Based on the above condition, the tank volume should be:

$$\text{Daily Demand} = \text{Daily consumption} * \text{No. of inhabitants} = 60*3 = 180\ L$$

Now, two times the demand will be 360 L, which is rounded to **400 Liters**. The accumulation tank should be chosen with capacity of 400 L, and able to withstand temperature of about 60°C.

From manufacturer's description, it is mentioned that the collector is able to provide hot water upto 450 L tank with energy demand 10kWhr for 4 – 6 persons. Since, this study house is inhabited by 3 persons with demand less than 450 L, it is safe to assume that, collector is able to produce enough energy to sustain this demand.

Considering the requirements and need for dual system setup, it has been decided to select **SPP-SCSW storage tanks** as accumulation tank for this project. This tank is manufactured by Solar panel plus [12], with various specifications offered like SPP Hydroflex, SPP Large volume, SPP Jacketed, and SPP bare steel type tanks.

This storage tank is available in various capacities ranging from 180 - 400 Liters and can be wall mounted by welding. As name suggests, this stratification tank comes as pre-designed to function with solar collector and able to attain stratification phenomenon.

Figure 24 SPP tank with stratification layers indicating temperature level of water [12]

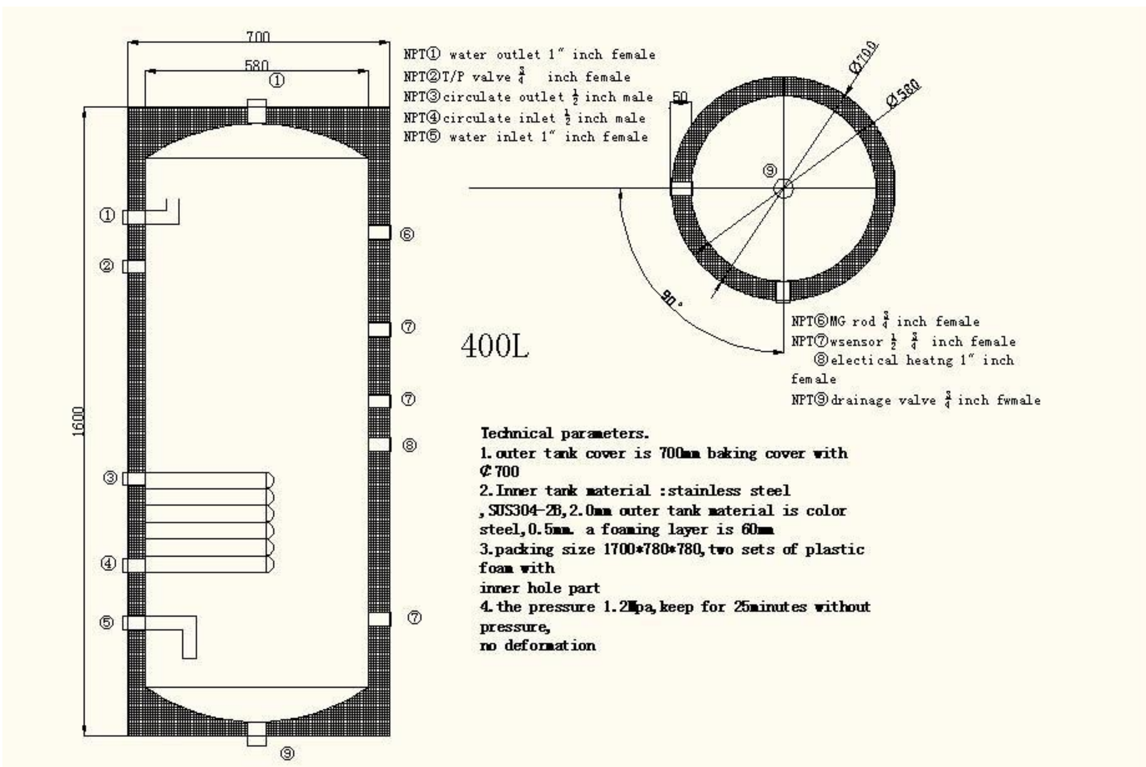


Figure 25 Brief description of SPP SCSW tank [12]

The specifications of the tank are given below:

Table 14 Dimensions of SSW storage tank [12]

Content	Values
Capacity of tank	400 Liters
Weight of tank	80 kg
Diameter	700 mm
Insulation thickness	60 mm
Inner tank thickness	2 mm
Diameter of coil	12 mm
Length of coil	35 mm

This storage tank comes equipped with Backup Electrical element, Thermistors, Manual control, Sediment reduction and Inner lining. These features are explained below:

6.9.1. Backup Electrical Element

This is a pre-installed heating element that, apart from solar system, can provide heating when external system is not able to meet the demand. This device also acts as electrical resistance that will be explained in next topic.

6.9.2. Thermistors

Thermistors are resistors type sensor device that depends on temperature level. When the temperature of water inside the tank increases, the resistance increases and when temperature decreases, resistance decreases. This thermistor is connected to the solar collector by means of twisted wires placed in upper and lower covers.

6.9.3. Manual control

This manual control designed by Honeywell ensures that water outlet temperature is adequate, and the flow is constant throughout the tank and collector.

6.9.4. Sediment reduction

Sediment formation in the tank leads to defect of the storage tank overtime. Thus, sediment reduction device is equipped to prevent building up of sediments in cold water inlet.

6.9.5. Inner Lining

This interior of the tank is coated with ceramic porcelain to prevent corrosion, while high silica lining in the interior of tank enables tough surface for hot water.

6.10. Prevention of Bacteria

The importance of prevention is to control formation of lethal bacteria, Legionella, which causes legionella's disease if infested. This bacteria feeds on corrosion and stagnation caused inside storage tank and able to multiply growth when subjected to Ideal growth range of 25 - 45°C. At 45 - 50°C, it is able to survive but can't multiply. From 50 - 70°C, 90% of bacteria dies between 2 – 120 mins. **Above 70°C**, the bacteria die instantly.

In order to control legionella, following steps should be considered:

- Hot water should be stored over temperature of 60°C and above, and cold water temperature should be below 20°C.
- Hot water should be used continuously or drawn out randomly at times when the house is unoccupied. This prevents stagnation promoting legionella's growth.
- Control of corrosion is necessary step that should be taken always to prevent bacteria growth, and also to increase lifetime of the system.
- The system should be maintained regularly and inspected periodically to check for services.
- Proper insulation for the storage tank is needed which restricts nutrients needed for bacteria growth [14].

Fortunately, the storage tank chosen, ***SPP - SCSW***, comes equipped already with safety features to prevent this possible bacterium growth. Still, it is responsibility of the tenants to inspect tank periodically and draw out hot water regularly.

6.11. Electrical resistance

Besides following above prevention methods, the manufacturer has also provided a heating element that provides electrical resistance to prevent growth of bacterium.

This heating element has thermometer that monitors the temperature level of the hot water in the tank. During hotter months, there is no problem with meeting the desired hot water temperature and thus, the heating element is mostly not functional. But during colder months, when the solar collector is not able to meet desired hot water temperature, additional heating is provided by this element.

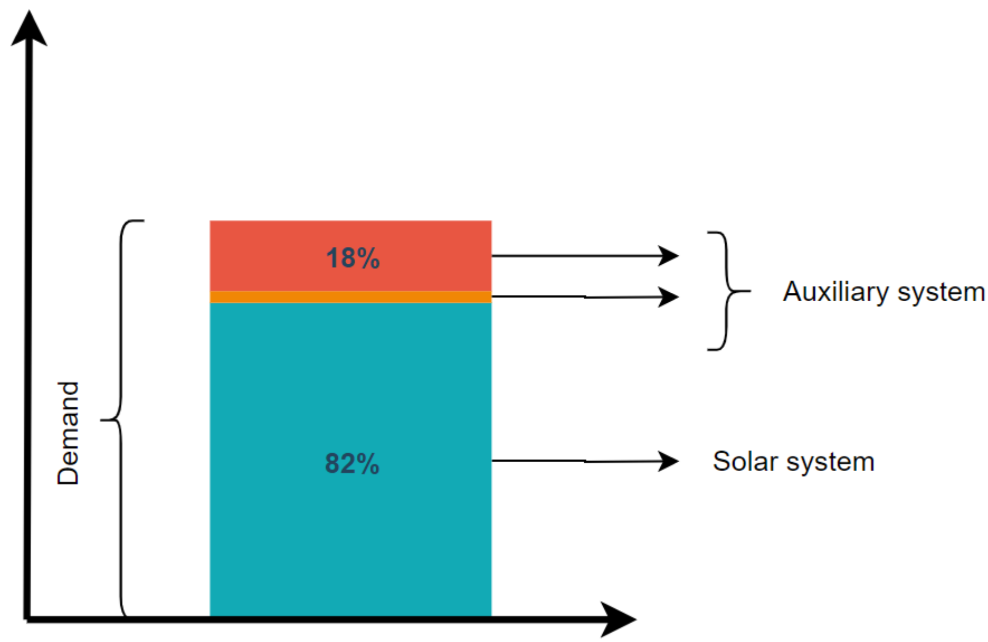


Figure 26 Energy balance of two systems

Together with gas boiler, these auxiliary systems are responsible to always meet the desired hot water temperature in the storage tank throughout the year. The heating element described by the manufacturer cannot solely cover the demand left out by the solar collector, due to limited nature of backup system. It acts merely as safety feature and gas boiler should be the main auxiliary system as it can be tuned up later according to needed demands.

7. SUPPLY FOR SWIMMING POOL

In order to utilize the overproduced energy from solar collector during hotter months, this excess production is directed to external source, which in this case is an **uncovered swimming pool**. This swimming pool is constructed outside the study house and the transfer fluid carrying heat is passed through the swimming pool heat exchanger where the pool water is circulated.

Solar system is the most cost-efficient method to heat swimming pool as it is not dependent on weather mostly. This means that regardless of geographical location, solar system can work for any pool water heating.

First, in order to realize this, the swimming pool area and volume of water that can be accommodated has to be analyzed.

The proposed swimming pool has following dimensions:

- Length = 10 m
- Width = 5 m
- Depth = 2 m

The existing solar system, although can't meet the complete demand for heating pool water, is able to provide at least considerable contribution. Required temperature level for pool water is about **20 - 25°C**.

7.1. Setup of circuit

This setup requires following systems that needs to be connected to the collector circuit:

- Filter
- Pump
- Control valve

7.1.1. Filter

Filter acts as passage for water flow from pool to collector and it removes any solid particles, leaves or debris in the water as it can damage the collector circuit.

7.1.2. Pump

Pumps here are mainly for circulation of water from and to the collector. During hotter months, the pool temperature can be higher than 25°C, in which case the water can be circulated to collector at nights to cool down the temperature.

7.1.3. Control Valve

Control valves are used to monitor the pool temperature and switches the circulation on and off depending on the hot water. Control valves can also be automated to control the flow rate of water to the collector to obtain desired temperature.

7.2. Overproduction of collector

The collector system from this project is able to provide considerate heating for this uncovered outdoor swimming pool because of the overproduction caused during summer months. Overproduction happens usually from *April through October* as follows:

Table 15 Results of Overproduction

Months	April	May	June	July	Aug.	Sept.	Oct.	Total [kWhr]/yr
Overproduction	151.89	327.87	282.12	336.62	381.19	111.05	25.73	**1616.47**

This solar system produces around **1616 kWhr** of excess energy per year which can be utilized for heating pool water. Temperature of pool water need not to be 60°C like domestic hot water. For comfortable swimming experience, 20 - 25°C is sufficient and heating is necessary only during swimming season and 4 -5 hrs. a day. This makes this solar system more effective for this application.

Advantages of this system:

The following advantages explains why solar system should be preferred over other conventional systems like electric heating or gas heating:

- Operational costs – Initial investment for the collector is all it takes for the system to operate and it can easily provide heating for 15 – 20 years without any service replacement.
- Fuel-less working – Solar energy is free of cost and it's the only energy needed for solar system to work. Unlike gas boiler, this system doesn't require any additional fuels.
- This pool also acts as backup tank for the solar collector replacing secondary storage tank. This prevents the stagnation in primary storage tank and also benefits the pool system.
- This system also serves as reversible unit to cool down the pool water during summer months where the water temperature can easily go as high as 30°C. This can be achieved by circulating the water to collector at night when the collector itself is cold.

Efficiency of this system depends on various factors:

- Size of pool: traditional housing pool can accommodate 4 – 5 pool for comfortable swimming.
- Swimming season: how long is the season for swimming, excluding colder months.
- Needed pool temperature: Usual temperature desired is about 20 - 25°C
- Collector orientation and tilt: This system is oriented towards south and azimuth angle of 0°
- Solar resource: depends on location and climate factors.

7.3. Heat Exchanger for Pool

The circuit connecting between Solar collector and the storage tank acts as **primary circuit**. This circuit is responsible for supply of DHW for the inhabitants. This circuit is connected by means of coil that transfer the heat from collector to the storage tank.

Now, this coil is connected to heat exchanger before it terminates at storage tank. This heat exchanger acts as **secondary circuit** connecting to the swimming pool.

This heat exchanger is not operational during colder months, that is, water doesn't flow through the heat exchanger due to the limited production of heating capacity by the collector. However, during summer months, the heat exchanger circuit (Secondary circuit) gets engaged and heat transfer takes place by means of convection. The coil carrying heat is partly transferred to the water flowing parallel to the coil flow in the heat exchanger.

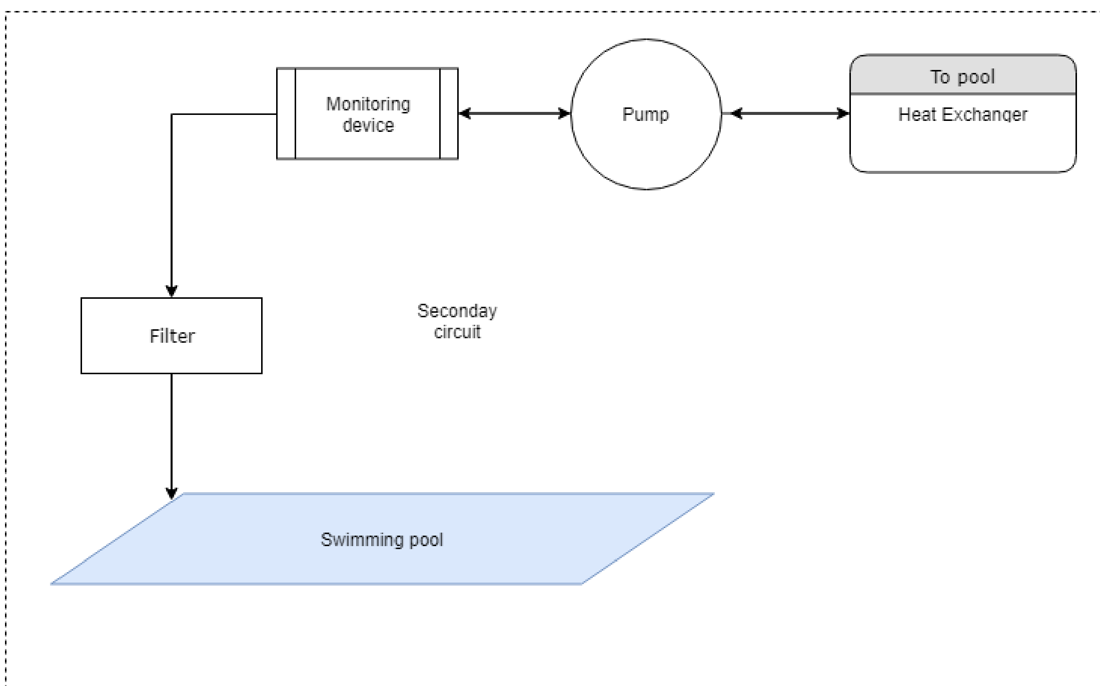


Figure 27 Block diagram illustrating secondary circuit

This secondary circuit is designed so that, it can't absorb total heat transferred by the coil to storage tank as the primary function is to provide heating water. This can be achieved by two ways:

Parallel and counter-flow – This mechanism is followed to determine between amount of overproduction happening in collector and the water temperature in the storage tank. It also considers the factor that if the water stored in the tank is retrieved for usage or if it's suspended for longer time.

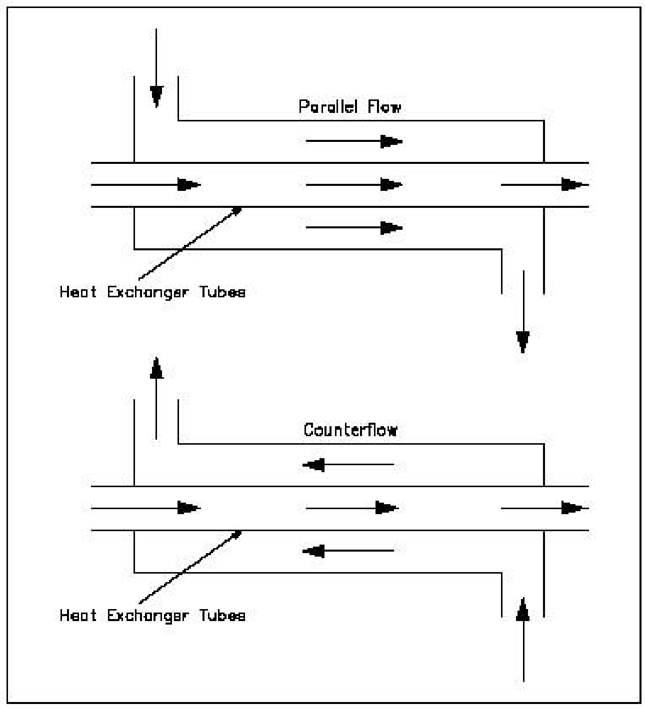


Figure 28 Parallel and counter-flow diagrams [15]

In parallel flow, the water in the heat exchanger flows in the same direction as the heat flow in the coil. This results in low heat transfer comparing to counter-flow. In counter-flow exchanger type, water flows perpendicular to coil flow and heat transfer is more too. This is because of the high average temperature difference at any part of the heat exchanger.

Another way to control the heat exchanger operation is to control via **monitoring device**. This device, with the help of sensors and valves, control the flow rate of the heat exchanger to adapt to the required demand in DHW heating process. This kind of device has pre-programmed microprocessors that, once installed, can function automatically without user supervision.

7.4. Monitoring Device

Before selecting appropriate monitoring device, it should be considered that the device should be able to read the temperature of pool and the temperature of coil in heat exchanger. This heat difference is essential for the device to execute control to pump.

For this, **SunReports Apollo1** monitoring system is selected, which supports two probes for measuring temperature, and digital data displayed to user via internet connection. The functionality of this device includes:

- Temperature sensors, that measure heat in swimming pool and heat required from solar collector.
- Current Transducers, that measure whether the pool pump is operational at that moment.
- Color-coded wiring, to differentiate the circuits from one another [16].

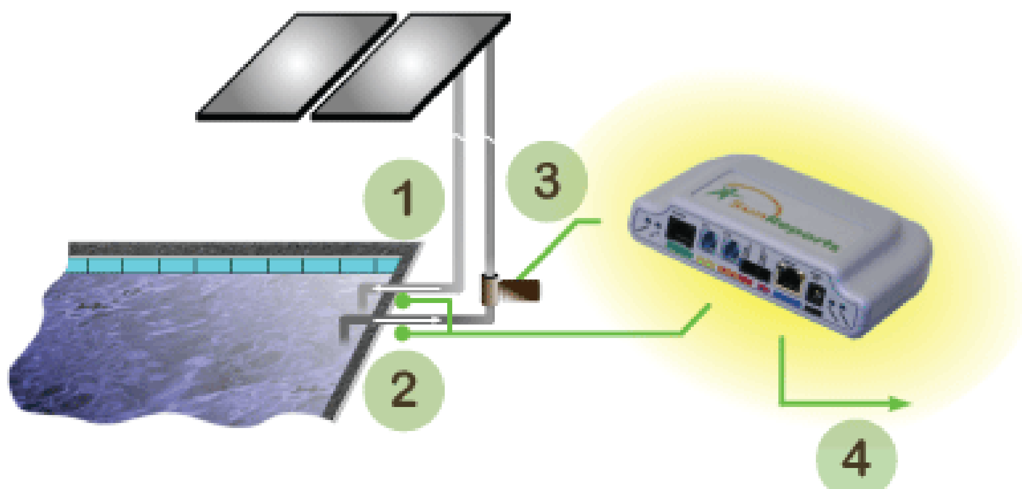


Figure 29 SunReports Apollo1 monitoring device

8. ENERGY CONSUMPTION

Since the **heating element and gas boiler** is powered through external source, the required consumption of electricity should be calculated. Both these systems are not functional during summer months; thus, only colder months are taken for calculation, that is, from *Nov. to March*.

Table 16 Energy consumed by Auxiliary systems

Months	Jan	Feb	Mar	Nov	Dec	Total
Demand	385.58	352.08	386.65	348.35	374.51	
Solar coverage %	52	71	99	43	25	
Max. output gain	202	248.2	384.6	150.3	94.3	
Auxiliary system	183.5	103.85	2.05	198.05	280.22	767.62

From the table above, it is visible that total electricity consumption by auxiliary systems accounts to be around **767.62 kWhr per year.** It is not viable to neglect auxiliary system and construct additional collector panel or improve collector efficiency as the difference is very minimal during colder months. Hence, Auxiliary systems are mandatory to cover the remaining demand if the house if off the perimeter of power grid or in isolated region.

Besides auxiliary systems, some elements of the solar collector system also require electricity to function. These elements include: Monitoring device, Sensors, Regulation control and other accessories. Although they require electricity, the need is so less comparing to production that it can be negligible.

Pump’s energy consumption can be greatly reduced by choosing an effective pump size and working rate. Smaller the pump, smaller is the operating and maintaining costs. Pool water should be circulated to the collector only when it’s necessary for heating or cooling. In order to remove debris or foreign materials, it’s not necessary to circulate through the filter. Most of this debris can be removed just with help of vacuum and skimmer. An energy effective pump can save energy upto 40%. [1]

8.1. Controller Module

This module is the brain of this solar system which can monitor the temperature level of inputs and outputs of water and controls the circulating pump. This controller module is provided with a relay switch that connects and interrupts the primary circuit of heat flow. Based on this project, **USDT 3004 Solar Differential Controller** [18] is selected.

This USDT 3004 controller unit functions based on microprocessor integrated unit that operates based on temperature difference between system return temperature of water and the temperature fed into the collector system. This device can present two temperature sensor values simultaneously and symbols in screen shows the current operation of the pump and circuit system.

Figure 30 USDT 3004 Controller Module

This controller has following specifications:

- Temperature sensors for 4 input levels
- Flow meter input to monitor flow rate
- Auxiliary relay unit to protect the system from overheating.
- Semiconductor relay for pump speed control
- Drain back control and Energy metering.

8.2. Operation of Module

This module operates on basic principle that when the temperature difference between input cold water and output hot water is on desired level, the circulating pump is turned ON. The collector sensor(S1) picks up the input temperature while the return sensor(S2) is placed before heat exchanger.

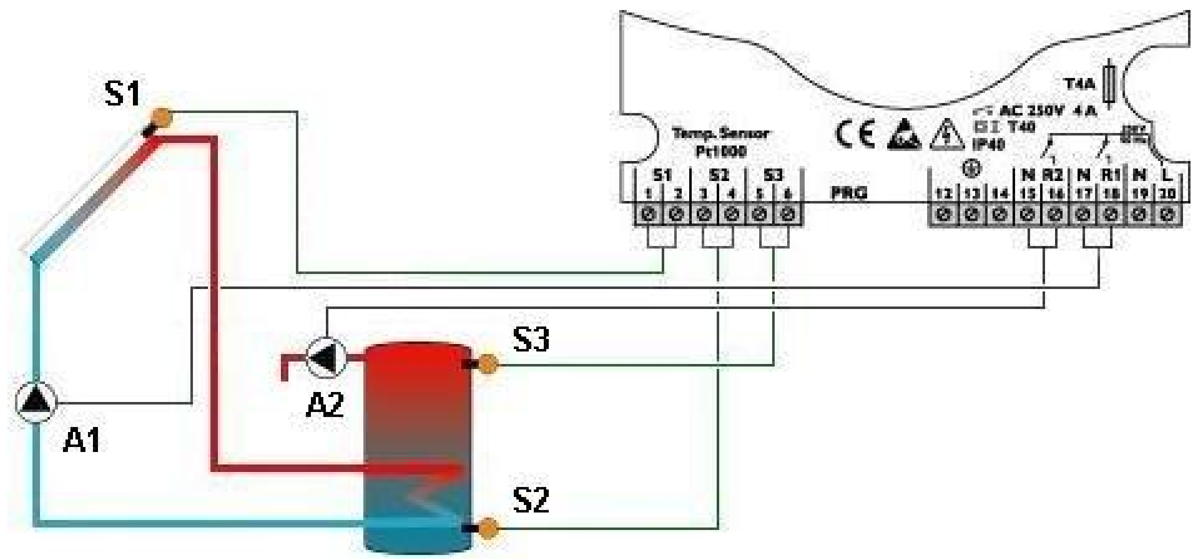


Figure 31 Circuit Diagram with placement of sensors and Auxiliary system controls [18]

Where:

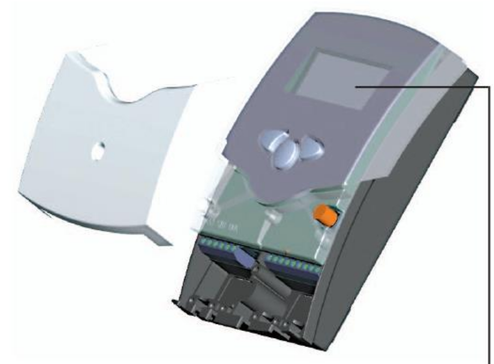
- S1 – Input temperature sensor,
- S2 – Return sensor,
- S3 – Auxiliary system sensor,
- A1, A2 – Auxiliary system, that controls the operation of Auxiliary system when the temperature difference is very minimal i.e., solar system production is not sufficient.

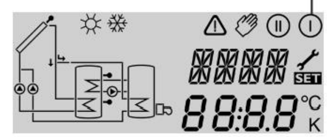
USDT 3004

THERMO TECHNOLOGIES

Overview

- System-monitoring-display
- Up to 4 Pt1000 temperature sensors
- semiconductor relay for pump speed control
- 3 basic system layouts to choose from
- Energy metering
- VBus®
- Function control
- Thermostat function (time controlled)
- Control of the system by ServiceCenter software possible
- User-friendly operation
- Housing with outstanding design
- Extra-low power consumption





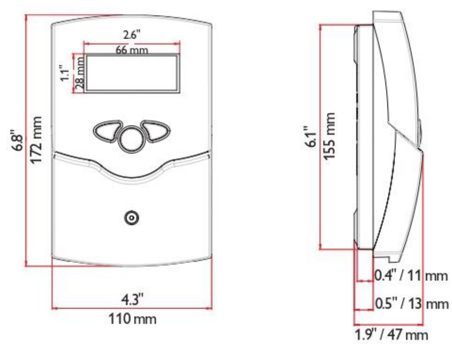
Included with the USDT 3004 :

1 × USDT 3004

1 × accessory bag
  1 × spare fuse T4A
  2 × screws and wall plugs
  4 × strain relief and screws

1 × manual

Additionally enclosed in the full kit:
  1 × sensor FKP6
  2 × sensor FRP6



Technical data

Housing: plastic, PC-ABS and PMMA

Protection type: IP 20 / EN 60529

Ambient temp.: 32 ... 104 °F [0 ... 40 °C]

Size: 6.8" × 4.3" × 1.9" 172 × 110 × 47 mm

Mounting: wall mounting, mounting into patch-panels is possible

Display: System screen for system visualization, 16-segment display, 7-segment display, 8 symbols for system status and operating control lamp

Operation: by 3 push buttons at the front of the housing

Functions: Differential temperature controller with optional add-on system functions. Function control, operating hours counter for solar pump, evacuated tube collector function, pump speed control, thermostat function, drainback and booster option, and energy metering.

Inputs: for 4 Pt1000 temperature sensors

Outputs: 2 semiconductor relays

Bus: VBus®

Power supply: 100 ... 240 V~

Standby power consumption: < 1 W

Switching capacities:

R1: 1 (1) A 100 ... 240 V~ (semiconductor relay)

R2: 1 (1) A 100 ... 240 V~ (semiconductor relay)

© 10259_usdt_3004.monus.indd

3 |

Figure 32 Overview of USDT 3004 controller module with specification details [18]

9. ACCESSORIES FOR SOLAR SYSTEM

Besides above mentioned devices and units, there are other parts of the system that is essential for smooth and safe operation of this solar heating system. These parts are described below:

9.1. Air vent valve

Air vent valves are installed to remove air that is accumulated in the system overtime. The need for removing air from the system is due to avoiding possible galvanic corrosion and corrosion. This can lead to compromising lifetime and performance of the system. This air buildup also affects the heating capacity as they form as air packets restricting proper flow of transfer fluid. For this system, the valve should be able to withstand maximum working pressure of about 110°C and maximum working pressure of 6 bars.

Figure 33 Model 362 Automatic Air vent valve [19]

This valve should be installed only in vertical position on top of collector system where air buildup is more frequent.

9.2. Thermometer

Since it’s a water heating system, temperature should be main factor which shouldn’t be compromise on. Hence, Thermometer is mandatory to monitor the temperature levels at various points of the system. For this system, 4 thermometers are required which will be installed in collector panel input and output for fluid temperature measurement, one in heat exchanger connected to pool and last one in the inlet of storage tank. These thermometers can be connected to ports of controller module to execute operation for pump and controlling flow rates.

9.3. Manometers

Manometers are used to monitor the pressure in the system. During Overproduction, temperature can go very high which results in higher pressure. This Over-pressure leads to leakage or even exploding of the system.

Figure 34 Manometer with digital reading

For this system, 2 manometers are required for both circuits i.e., one in swimming pool circuit after water pump and another after circulating pump carrying heat transferring fluid.

9.4. Check valves

Fluid and water flow in system can be one way in vertical flow due to force of gravity. But in horizontal flow, this is not the case. This is where application of check valves comes. Check valve, or **One-way valve** allows path of flow in only one direction. This valve prevents backflow of heated fluid or water back to the collector system, which can cause serious heat losses if not taken care of.

Material	Machined Brass
Flow rate	90 L/min
Max. supply Temperature	170°C
Max. supply pressure	14 bars

Figure 35 Solar Non-return valve (Check valve) [20]

9.5. Drain valves

This valve is used to drain the transfer fluid in collector system and water in storage tank circuit. Drain valves for storage circuit can be standard unit that doesn't has to be specifically chosen, but for fluid drain, valve should be chosen considering the reactive parameters.

Figure 36 Drain valve for Heating water systems [21]

9.6. Thermostatic Mixing valves

To prevent scalding in skin due to high temperature water in outlet, Thermostatic mixing valves are installed to achieve safe water level temperature for end-user's comfort. These valves use **Wax thermostat** technology for regulating temperature. This valve combines the hot water with cold water to achieve the desired temperature of 60°C.

Figure 37 Honeywell valve AM08 [22]

This valve is also responsible to prevent legionella disease by maintaining constant temperature of 60°C at the outlet.

9.7. Pressure and temperature valve

P&T valves are safety valves, present in every solar heating systems. They are responsible for preventing the system from excess pressure and temperature. This valve releases steam and hot water when the sensors detect exceeding values in the system.

Figure 38 P&T combi valve PTEM500

9.8. Isolation valves

Isolation valves are typically **ball valves or get valves** that interrupts the flow. These valves should be installed at various places of the collector system to differentiate the circuits for servicing and cleaning.

For this installations, 3 isolation values is needed, preferably get valves each installed at collector-heat exchanger system for isolating fluid flow circuit, heat exchanger-swimming pool to interrupt water supply and before storage tank to interrupt water flow into accumulator.

Figure 39 Easyflex compact isolation valves [23]

10. CIRCULATING PUMP

Circulating pumps are responsible for transfer of heat transferring fluids from and to the collector. The installation of solar collector will be on the roof of the house. This means there is atmosphere resistance gravity acting on the fluid. This antifreeze liquid should reach into the collector system where it is heated and then is fed into the heat exchanger system all by means of a circulating pump. Since this system is closed loop, that is, the same transfer fluid is recirculated again, the pump material should be considered for restricting air flow inside the circuit. For this, pumps made of Iron or Brass is considered as oxygen cannot enter into the circuit and corrode the collector system and other parts.

Below figure shows placement of pump in collector system:

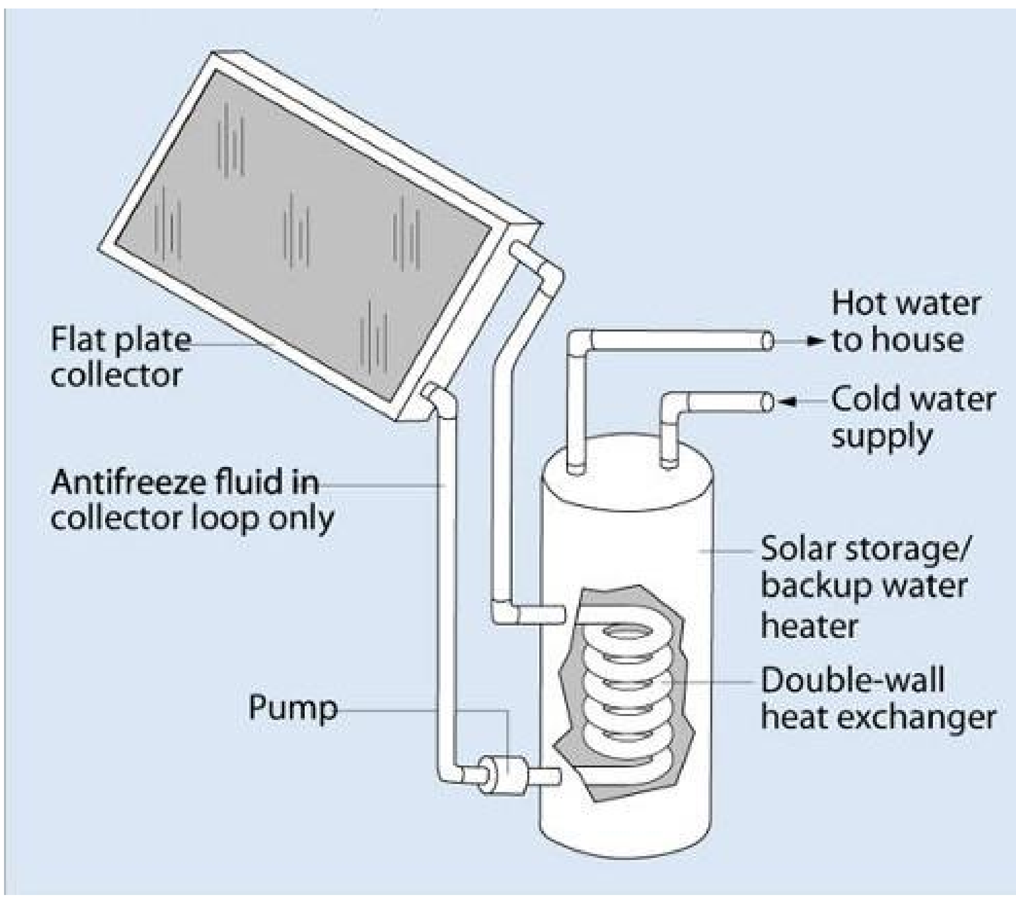


Figure 40 Placement of pump in collector system [24]

10.1. Selection of Pump

Modern circulating pumps are capable of differentiating variable flow rates in the collector system and adapt the pump circulation according to desired rate. Hence, it is not necessary to worry about the changing flow rates in the collector system.

Based on the study, it’s finalized to choose **Series 255 solar Pump** as the circulating pump. The reason to choose this pump, is due to features along with its function. This is a standalone pump station that has inbuild ***Thermometer, safety relief valve, Air vent valve, Flow meter, Pressure gauges and check valves***. All these safety necessities are included within this Pump station which combines this unit as a self-system on its own.

Figure 41 Series 255 Solar Pump [25]

This circulating pump can be controlled by the proposed controller module and the flow rate of fluid can be adjusted based on required output temperature needed. This pump serves also following features:

- Ball and check valves to prevent gravity flow of liquid during circulation.
- Separate ports to empty, flush and fill the system.
- **Air vent valve**, to remove buildup air inside the system.
- **Flow meter** installed to monitor the flow rate of fluid.
- **Thermometer** for display of input and output temperatures.
- **Pressure gauges** to monitor solar loop pressures.
- **Safety relief valves** to discharge the loop during over-pressure which can result in explosion.

This circulating pump serves multiple functions along with circulating the fluid. This reduces overall cost of the hydraulic circuit and also eases installation and maintenance processes. [25]

11. LISTING AND BUDGETING

Below tables lists the number of components and devices necessary for this proposed Solar Water heating system along with price (incl. taxes):

11.1. Collector system

Table 17 Budget for Collector system

Component	Number (or) value	Total Price
Hassler Omegasol S - Flat plate collector (Solar panel)	3	1860 €
To achieve orientation of 55° (Support Frame)	1	230 €
Sentinel R100 thermal fluid (Transfer fluid)	10 L	52 €

Total = 2142 €

11.2. Auxiliary system

Table 18 Budget for Auxiliary system

Component	Number (or) value	Total Price
VIADRUS Grand G 36 (Natural Gas Boiler)	1	460 €

Total = 460 €

11.3. Primary Circuit

This circuit deals with components connecting storage tank with collector system:

Table 19 Budget for primary circuit

Component	Number (or) value	Total Price
USDT 3004 Solar Differential Controller (Controller module)	1	310 €
Series 255 solar Pump (Circulating pump)	1	407 €
SPP SCSW tank Capacity of 400 Liters with inbuilt Electrical Resistance unit (Storage tank)	1	1350 €

Total = 2067 €

11.4. Secondary Circuit

This circuit deals with components installed for Swimming pool operation:

Table 20 Budget for secondary circuit

Component	Number (or) value	Total Price
SunReports Apollo1 with 4 temperature ports and flow metering system (Monitoring system)	1	390 €
(Filter) for debris removal in pool water	1	80 €
(Pump) for water supply from pool	1	380 €
(Heat exchanger) For heat transfer between different fluids	1	540 €

Total = 1390 €

11.5. Accessories

Table 21 Budget for Accessories

Component	Number (or) value	Total Price
Manometers	2	32 €
Isolation valves	3	18 €
Copper pipes of **ϕ20 mm**	40 m	120 €
Pressure & Temperature valves	1	20 €
Drain valves	1	10 €
Thermostatic mixing valve	1	70 €

Total = 270 €

11.6. Total cost of system

Added costs are accounted to be:

Table 22 Budget for Entire system

Contents	Cumulative price €
Collector system	*2142*
Auxiliary system	*460*
Primary Circuit	*2067*
Secondary Circuit	*1390*
Accessories	*270*
Other installation costs	*500*
Total price	*6830*

This total amounts to **6830 €** which is calculated with state and international taxes in mind.

Total in € = 6830 €

(Conversion rate as of May 2019, 1 € = 25.74 Kč)

Applying conversion rate, Total price in CZK = **175786.50 *Kč***

12. ECONOMIC IMPACT

One of the best things of the solar system is that economic impact it has on the inhabited house and also on the society, because of the usage of global solar resource. An active solar system needs initial costly investment. But once it is set up and operational it starts gaining profit and in few years the investment will be gained back. This period in which the profit gained is neglected as investment fund, is called as **payback period.** After this investment is recovered, the system yields profit until its lifetime.

To study the economic impact of the system, the following data is needed:

- Annual demand – energy consumed in the study house for annual year.
- Production - Energy supplied by this solar system.
- Total investment cost for setting up the system.

Now substituting known values for the above parameters from previous calculations:

For Annual demand in the study house, it is established with data of Average consumption of drinking water with temperature difference and specific capacity of water. This value is given as **4250.25 kWhr.**

However, the value obtained for solar energy production is based on theoretical calculation and in real, solar fraction is applied which is determined to be **82%** considering the region of Ostrava. With this percentile of energy, the obtained result is about **3482.63 kWhr.**

The above result defines that before solar system installation, the house was supplied by Auxiliary system completely for annual production of *3482.63 kWhr per annual year.* In this case, it is Natural Gas boiler which is able to save on consumption due to installed solar system.

The economic impact for this installed system is not only from the solar system only, it is also partly from the pumps used in the construction. These pumps need electrical energy to operate which in turn reduces the savings of the solar system. So, it is necessary to determine economic savings with keeping in mind, both the energy generated by solar heating and energy consumed by the circulating pumps.

12.1. Energy consumption of pumps

Since this system is operated by two pumps, one for pumping of antifreeze liquid in collector loop and another for circulating of pool water into the heat exchanger, Energy consumption of both the pumps is calculated to determine accurate energy savings.

12.2. Pump 1

"Pump 1" is labelled for the pump that is placed in the collector circuit. This pump is responsible for pumping the heat carrying fluid into the collector. Hence, this pump is operational every time the controller module detects the heating capacity of the antifreeze liquid. The chosen pump is *Series 255 solar Pump* with max. power rating of **40 W.**

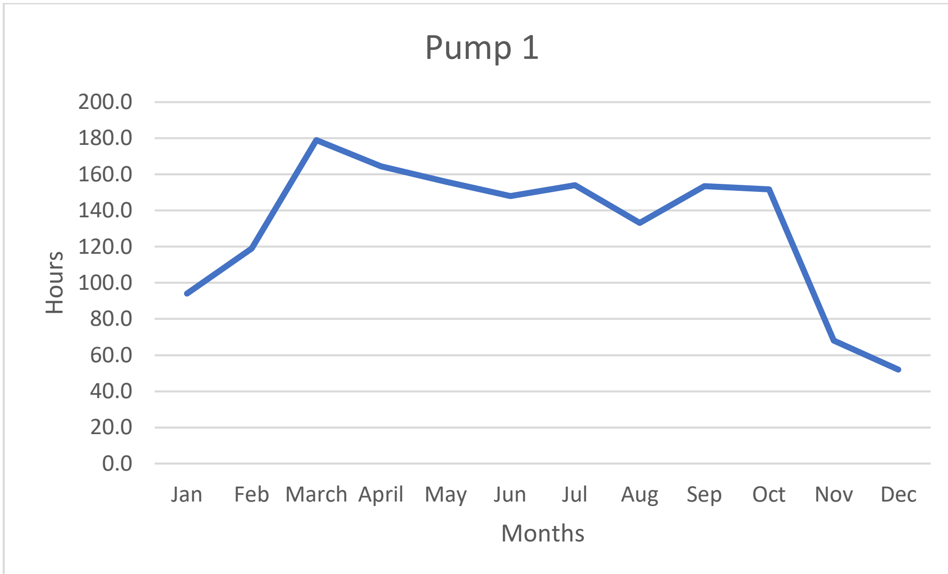
Once the working hours of pump is known, it is combined with the power capacity(=40W) and the result is the total energy consumed by pump 1. To find the working hours, the data from Meteonorm is applied again to study the number of hours in each month when solar energy is incident and able to provide sufficient energy for solar heating.

The following table shows the total working hours of pump according to the data of solar radiation in Ostrava region:

Table 23 Working hours of Pump 1

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Solar fraction	52%	71%	99%	100%	100%	100%	100%	100%	100%	100%	43%	25%
Max. gain	202.1	248.2	384.6	516.4	690.4	618.8	673.4	713.4	435.7	371.4	150.3	94.3
Useful gain	202	248	384	364	362	336	336	332	324	345	150	94
Useful/Max. gain	1	1	1	0.71	0.53	0.54	0.50	0.47	0.75	0.93	1	1
Pump 1	94	119	179	233	297	272	308	286	206	163	68	52
Pump 1 real	94	119	179	164	155	148	154	133	153	151	68	52

The real pump values are determined by useful work done, that is exact hours of pump operation excluding the overproduction factor. This is because the overproduced heating is utilized by secondary circuit with own pump. Below graph shows the working hours distribution for each month.



Graph 6 Working hours of pump 1

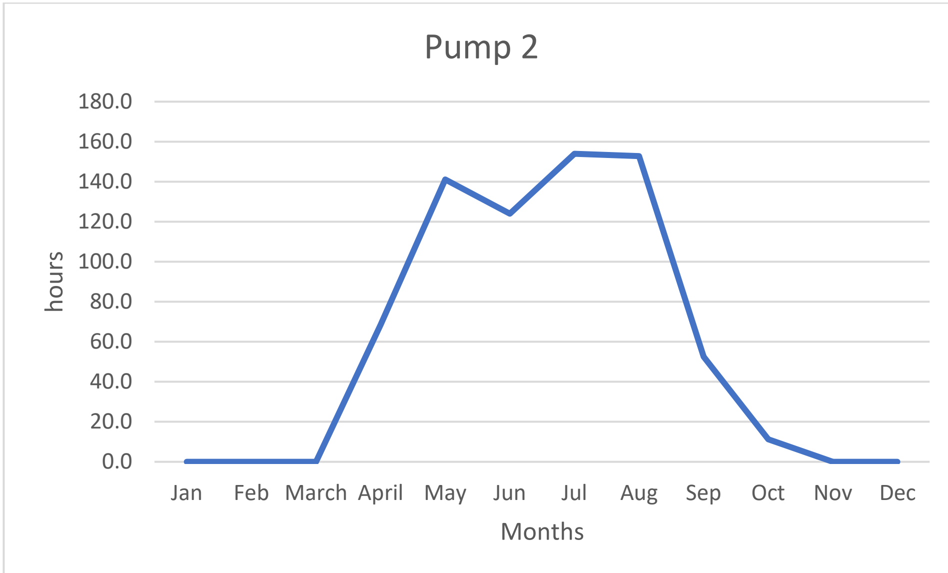
12.3. Pump 2

"Pump 2" is labeled for standard water circulating pump for swimming pool. Since this pool is heated by solar collector during summer months because of overproduction, this pump is operational only during summer, i.e., from April until September. The values are considered for summer months and is given as:

Table 24 Working hours of Pump 2

Months	**April**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Overproduction (kWhr)	151.89	327.87	282.12	336.62	381.19	111.05	25.73
Over supply/Demand	0.29	0.47	0.46	0.50	0.53	0.25	0.07
Pump 2 real	68.5	141.1	124.0	154.0	152.8	52.5	11.3

The following graph shows the working hours for pump 2:



Graph 7 Working hours of pump 2

Since the pump 2 for swimming pool is standard pool pump type, the power rating is around **90 W**. This large pump is capable of circulating large volume of water from and to the pool.

Energy consumption

The energy consumption for both these pumps are given by:

$$Energy\ consumption = Power\ rating * Annual\ working\ hours$$

For pump 1,

Energy consumed for pump 1 $= 40\ \mathrm{W} * 1573\ \frac{\mathrm{hrs}}{\mathrm{yr}} * 1/1000$ = ***62.91 kWhr/yr***

For pump 2,

Energy consumed for pump 2 $= 90\ \mathrm{W} * 704\ \frac{\mathrm{hrs}}{\mathrm{yr}} * 1/1000$ = ***63.36 kWhr/yr***

Total energy consumed = 126.27 kWhr/yr

12.4. Energy Savings

$$Energy\ savings = Energy\ generated\ by\ solar\ system - Energy\ consumed\ by\ pumps$$

Energy savings per year = 3482.64 kWhr – 126.27 kWhr = ***3356.37 kWhr***

The work carried out by the pump 2 for swimming pool cannot be neglected in case of Natural gas heating, since the pool water still has to circulate into the boiler. Hence, the energy saving without considering energy consumption of pump 2 accounts to **3419.73 kWhr per year**.

The above calculated value is the amount of energy which is able to save because of the solar system. But to achieve this energy demand via other conventional systems like Gas boiler, much more energy is needed due to the efficiency of the Gas boiler.

Our gas boiler has efficiency of 92%. This means the operation energy consumed will be higher than saving and is given as:

$$Energy\ consumed\ for\ Natural\ gas\ = \frac{Energy\ saving\ from\ solar\ collector}{Efficiency\ of\ the\ gas\ boiler}$$

$$Energy\ consumed = \frac{3419.73}{0.92} = \mathbf{3717.09}\ \boldsymbol{kWhr/yr}$$

12.5. Economic saving

Economic impact is determined by cost of energy needed for auxiliary system. This can be cost of fuels, electricity, gases or chemicals depending on the system used. In our case, Natural gas boiler is used, and cost is calculated for 1kWhr of natural gas.

Average cost for 1 kWhr of natural gas in Czech Republic as of May 2019 is about ***1.27 Kč.*** (retrieved from database of *tzb-info* website)

So, Annual savings in cost is calculated from,

$$Economic\ saving = [Cost\ of\ fuel] * [Energy\ saving]$$

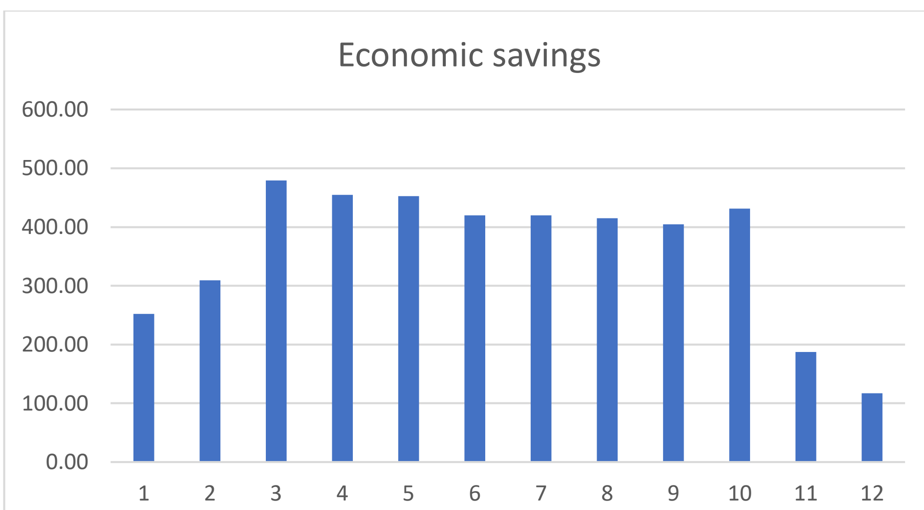
$$Economic\ saving = 1.27\frac{Kč}{kWhr} * 3419.73\ kWhr = \mathbf{4343.05}\ \boldsymbol{K}č\boldsymbol{/yr}$$

The following table shows the Energy and Economic saving obtained from our solar system:

Table 25 Energy and Economic saving

Months	Energy Demand	Useful gain from the system	Working hours of pump	Energy consumption of pump	Energy savings	Economic Savings
Jan	385.58	202.10	82.00	3.76	198.34	251.89
Feb	352.09	248.24	114.00	4.76	243.48	309.22
March	386.66	384.65	182.00	7.16	377.49	479.41
April	364.54	364.54	84.10	6.58	357.96	454.61
May	362.48	362.48	177.34	6.24	356.24	452.42
Jun	336.64	336.64	167.11	5.92	330.72	420.02
Jul	336.80	336.80	195.06	6.16	330.64	419.91
Aug	332.23	332.23	181.72	5.33	326.90	415.16
Sep	324.69	324.69	57.44	6.14	318.55	404.56
Oct	345.69	345.69	160.00	6.07	339.62	431.32
Nov	348.35	150.30	61.00	2.72	147.58	187.42
Dec	374.52	94.29	44.00	2.08	92.21	117.11
Total	**4250.26**	**3482.64**	**1505.78**	**62.91**	**3419.72**	**4343.05**

Below tables illustrates economic savings that can be saved from our solar system:



Graph 8 Economic savings for annual year.

12.6. Payback period

From this economic saving parameter, payback period for our system can be obtained. The total saving obtained from our system for an annual year account to be **4343 kWhr** per year. Now in order to gain profit from this system, the investment amount needs to be returned back.

Total investment for our system = ***175786 Kč*** *including the installation costs*

Below table shows the increase in savings every five year timeframe:

Table 26 Total payback period

year(s)	**Savings**
1	4343.047
5	21715.24
10	43430.47
15	65145.71
20	86860.95
25	108576.2
30	130291.4
35	152006.7
40	**173721.9**

For our solar system, the payback period takes about **40 years**, which means that the solar system is able to gain profit only after this time period. However, in real practice the payback period is much lower (around 15 to 20 years). This is due to the subsidy and tax exemptions from the Czech Republic for renewable clean energy like solar heating.

13. ENVIRONMENTAL IMPACT

Solar system has great positive impact and one of the main reasons to replace conventional heating systems. Both Natural gas and electricity systems results in emission gases that are harmful for the environment. Although electricity in its final form can be called as clean energy, the production of the electricity is either of the following methods: *Thermal powered, nuclear powered or Gas powered stations*. Every one of the above plants has effect on the environment by the release of harmful emission gases rich in **CO_2, SO_2, NO_x or dust particles**.

Solar powered systems are clean energy both in production and in end form. This is due to source of sunlight with heat radiations. This results in combustion-less energy that can be utilized directly for our system.

The heat demand is not entirely covered by solar system in our case. Hence our study house is not emission free. However, the emission is greatly reduced, and difference will be explained below.

First, annual energy saving is used to determine the emission that was produced before our installation.

Annual energy savings = **4250.25 kWhr**

This was the required amount, that was obtained from our Natural Gas boiler every year. To obtain this amount of energy, our boiler with efficiency of 92% needs

$$Amount\ of\ Natural\ Gas\ required\ (in\ m^3) = \frac{4250.25}{0.92 * 9.5} = \boldsymbol{483\ m^3}$$

Where the factor ‘9.5’ is the calorific value of the natural gas. [$C_p = 9.5\ kWhr/m^3$]

To measure the amount of emission gases produced by this system, data of various emissions from the database of Czech Republic Environmental agencies [26] is retrieved. These emissions include CO_2, SO_2, C_xH_y, CO, NO_x and dust particles.

This below table shows the various emissions values according to their emission content per m^3:

Table 27 Emissions from Natural gas

Emissions	CO_2	SO_2	NO_x	C_xH_y	CO	Dust
Units	(gms/kWhr)	(gms/m^3)				
Values	200	0.0004	1.6	0.064	0.32	0.02

Calculations of each emission contents is given:

$$\text{Volume of } CO_2 \text{ emissions} = 4620\ kWhr * 0.2\ Kg/kWhr = \mathbf{924\ Kg}$$

$$\text{Volume of } SO_2 \text{ emissions} = 483\ m^3 * 0.4 * 10^{-6} \frac{Kg}{m^3} = \mathbf{0.00019\ Kg}$$

$$\text{Volume of } NO_x \text{ emissions} = 483\ m^3 * 0.0016 \frac{Kg}{m^3} = \mathbf{0.773\ Kg}$$

$$\text{Volume of } C_xH_y \text{ emissions} = 483\ m^3 * 0.064 * 10^{-3} \frac{Kg}{m^3} = \mathbf{0.03\ Kg}$$

$$\text{Volume of CO emissions} = 483\ m^3 * 0.32 * 10^{-3} \frac{Kg}{m^3} = \mathbf{0.154\ Kg}$$

$$\text{Volume of Dust particles} = 483\ m^3 * 0.02 * 10^{-3} \frac{Kg}{m^3} = \mathbf{0.0096\ Kg}$$

The total emission produced in the family house for an annual year is about **925 Kg** of which more than 98% of the emission is harmful CO_2 gases. Since our installed system cannot cover overall demand, this system is still operational in house as auxiliary system. This means that the emission gases are still there, but comparatively less.

Our Natural gas boiler covers **18%** of the demand, which is about 765 kWhr. With efficiency (=92%) of the boiler, it is about **831.52 kWhr or 87.52 m^3**. For this volume of Natural gas, emitted gases accounts to be **166.5 Kg** which will be emitted from our system. Apart from this, Emissions from Electricity powered components also needs to be considered.

This system is functional also because of the two pumps, that are installed for circulation of fluids and pool water. These are powered by electricity and thus emission gases during production needs to be calculated.

The emission values during electricity production is again retrieved from Czech Republic Environmental agencies and are given below:

Table 28 Emissions from Electricity production

Emissions	CO_2	SO_2	NO_x	C_xH_y	CO	Dust
Values (Kg/kWhr)	1.17	0.0018	0.0015	$0.11*10^{-3}$	$0.1*10^{-3}$	$0.093*10^{-3}$

Annual electricity needed for both pumps account to **126.27 kWhr.** To determine emission gases for this:

$$\text{Volume of } CO_2 \text{ emissions} = 126.27\ kWhr * 1.17 \frac{Kg}{kWhr} = \mathbf{147.74\ Kg}$$

$$\text{Volume of } SO_2 \text{ emissions} = 126.27\ kWhr * 0.0018 \frac{Kg}{kWhr} = \mathbf{0.23\ Kg}$$

$$\text{Volume of } NO_x \text{ emissions} = 126.27\ kWhr * 0.0015 \frac{Kg}{kWhr} = \mathbf{0.189\ Kg}$$

$$\text{Volume of } C_xH_y \text{ emissions} = 126.27\ kWhr * 0.11 * 10^{-3} \frac{Kg}{kWhr} = \mathbf{0.014\ Kg}$$

$$\text{Volume of CO emissions} = 126.27\ kWhr * 0.1 * 10^{-3} \frac{Kg}{kWhr} = \mathbf{0.013\ Kg}$$

$$\text{Volume of Dust particles} = 126.27\ kWhr * 0.093 * 10^{-3} \frac{Kg}{kWhr} = \mathbf{0.012\ Kg}$$

Total Emissions from electricity used for pumps accounts to **148.2 Kg.** To prevent this emission from electricity, Solar photovoltaic panels can be installed which can yield clean renewable energy without harmful gas emissions.

13.1. Total Emissions

Total emissions are determined by taking in account the emission saving from solar system with emissions from electricity needed and emissions from auxiliary system.

This is given as:

$$Emissions\ saved = [Natural\ gas_{emi}(100\%)]-[\ Auxiliary\ system_{emi}(18\%)]-[\ Electricity\ used_{emi}]$$

Emissions savings = 925 Kg – 166.5 Kg – 148.2 Kg = **610.3 Kg**

From the calculated emission results, this newly installed solar system is able to prevent **66%** of the emissions released into the environment.

14. CONCLUSIONS

From the Economic and Environmental evaluation of this solar system, it is visible why solar systems should be replaced for a green and clean environment. Although the initial investment and setup cost is higher, the return of investment is promising with payback year of 40 years without considering subsidies from the Czech government. Apart from this, the hamily house will also benefit from Energy and economic savings of ***3356.37 kWhr*** and **4343.05 Kč/yr** respectively.

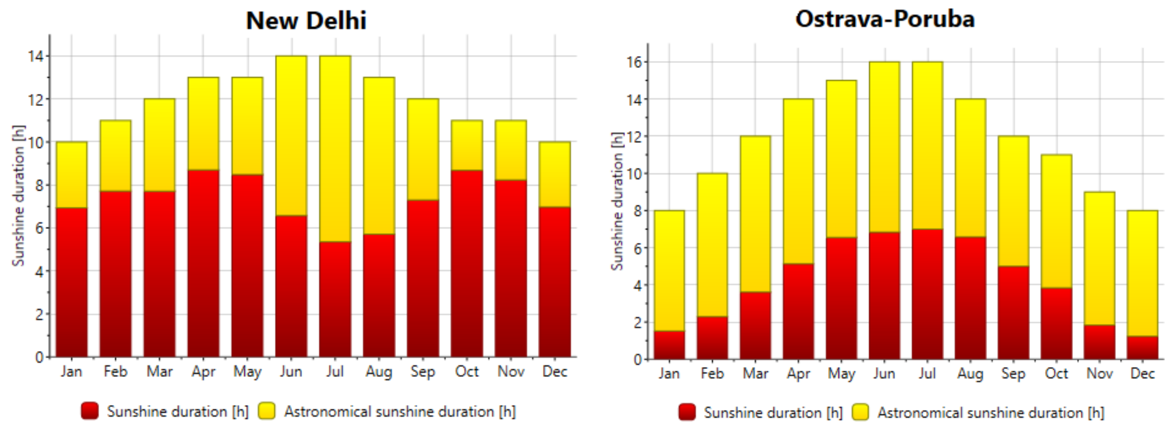
15. GEOGRAPHICAL COMPARISON

This solar system is proposed based on the requirements and climatic conditions of the Ostrava region. The temperature and radiation data are taken for this location and it differs from region to region. To compare this heating system with **Geographical part of India**, the temperature and radiation values for that location is taken.

For this comparison, **New Delhi** is considered as the installation city and the inhabitants in the family house and their demand are taken such that it resembles the same requirement as the house on Ostrava.

Figure 42 Location of New Delhi in map of India

To determine the temperature and radiation difference between Ostrava(CZ) and New Delhi(IND), METEONORM [5] application is used for obtaining values:



Graph 9 Average sunshine durations

It is seen that average sunlight duration in New Delhi lasts longer time than Ostrava during colder months i.e., from September to March. This is due to **Tropical climate** in India where snow is not so much prevalent unlike Ostrava. This makes this solar system more practical to install in this location as the solar fraction will be higher. Below data table shows the radiation and temperature difference between these two locations:

New Delhi

	Gh kWh/m²	Gk kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	118	189	37	161	13.2	7.8	1.4
February	137	187	40	167	17.3	10	1.5
March	188	209	50	214	23.2	12.5	1.6
April	207	182	70	189	29.6	12.9	1.7
May	222	164	96	165	32.5	17.6	1.9
June	197	137	107	111	32.5	22.1	1.7
July	167	120	103	83	31.3	25.2	1.7
August	160	129	91	93	30.4	25.1	1.6
September	171	168	71	146	29	22.9	1.2
October	165	190	66	147	25.4	17.3	0.7
November	129	182	48	142	19.6	12.4	0.6
December	115	181	41	143	14.8	9.2	0.9
Year	1976	2037	820	1762	24.9	16.2	1.4

Ostrava-Poruba

	Gh kWh/m²	Gk kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	26	56	14	45	-1.3	-3.9	4.5
February	42	74	23	55	0.4	-2.8	4
March	78	100	45	74	3.5	-0.6	3.9
April	121	134	61	110	9.5	3.3	3
May	153	140	84	112	14.5	8.8	2.9
June	159	135	91	109	17.5	11.8	2.7
July	164	143	86	126	19.3	13.5	2.8
August	144	143	74	120	18.9	13.4	2.5
September	94	110	47	92	13.9	9.3	2.7
October	56	82	34	55	9.8	6.2	3.3
November	27	49	17	36	5.2	2.3	3.8
December	19	38	13	26	-0.1	-2.4	4.3
Year	1079	1204	589	961	9.3	4.9	3.4

Figure 43 Data tables for both locations

With this data, it is determined that even with two panels, this solar system is able to meet the demand of the family house. This is due to the high solar fraction in the colder months compared to Ostrava which can supply the need without auxiliary system. This results in lower investment cost and maintenance with shorter payback period.

Due to the nature of the region, the need for hot water is very less and usage is limited to sanitary purposes mostly. Hence, this system may have higher solar fraction, but it is not practical to install due to cost-benefits comparison. However, this is not the case for Solar powered electricity. Photovoltaic panels are a huge beneficial commodity for regions like New Delhi which can supply the demand for electricity rather than hot water.

REFERENCES

[1] "Solar collector," 2019. [Online]. Available: https://oze.tzb-info.cz/solarni-kolektory.

[2] "Data for use of Solar systems," [Online]. Available: https://www.tzb-info.cz/tabulky-a-vypocty/100-zakladni-udaje-pro-vyuzivani-slunecni-energie. [Accessed 2019].

[3] "Renewable energy world," February 2004. [Online]. Available: https://www.volker-quaschning.de/articles/fundamentals4/index.php. [Accessed April 2019].

[4] "VIADRUS," [Online]. Available: https://www.viadrus.cz/plynove-kotle/plynovy-kotel-stacionarni-g42-g42-eco-26-cz8.html. [Accessed March 2019].

[5] "Meteonorm Database," December 2017. [Online]. Available: https://meteonorm.com/en/.

[6] "Hot water systems," hassler alternative energie gmbh, [Online]. Available: https://hassler-energia.ch/warmwasser/. [Accessed 2019].

[7] " Institute for Solar Technology," [Online]. Available: http://www.spf.ch/index.php?id=111&L=6&no_cache=1.

[8] "Energy sage panels," February 2019. [Online]. Available: https://www.energysage.com/solar/101/wiring-solar-panels-in-series-or-parallel/.

[9] "Thermal fluids," Sentinel products, [Online]. Available: https://www.sentinelprotects.com/uk/products/r100-solar-thermal-fluid. [Accessed 2019].

[10] V. P. D. L. R. W. M. . Vasta, "Adsorption-compression cascade cycles: an experimental study. Energy Conversion and Management," 2018.

[11] "Setting up storage tank," [Online]. Available: http://www.solar365.com/solar/thermal/how-set-storage-tank-solar-thermal-space-heating.

[12] "Solar storage tanks," Solar panel plus, 2014. [Online]. Available: http://www.solarpanelsplus.com/products/solar-storage-tanks/.

[13] "Sun horizon," [Online]. Available: http://www.sunhorizon-project.eu/technologies/.

[14] "Managing legionella in water systems," [Online]. Available: http://www.hse.gov.uk/healthservices/legionella.htm.

[15] "Heat transfer," [Online]. Available: https://www.myodesie.com/wiki/index/returnEntry/id/2993.

[16] "Apollo residential system," Sun Reports, [Online]. Available: http://www.sunreports.com/products.html.

[17] "Energy USA," [Online]. Available: https://www.energy.gov/energysaver/installing-and-operating-efficient-swimming-pool-pump#309376-tab-0.

[18] "Solar Differential controller," Thermo Technologies, [Online]. Available: http://www.thermomax.com/Solar_Controller_3002.php.

[19] "ART 362," iTap, [Online]. Available: http://www.itap.it/heating-valves/AIR-VENT-VALVES-AND-SAFETY-VALVES/219/automatic-air-vent-valve.asp?id_m=13.

[20] "Valves and plumbing," Reliance valves, [Online]. Available: http://www.rmc.com.au/type_products/valves-plumbing/.

[21] "EHC," [Online]. Available: https://www.electric-heatingcompany.co.uk/shop/sp01897-12-drain-valve/. [Accessed 2019].

[22] "Water alarms," Honeywell, [Online]. Available: https://www.honeywellhome.com/en/products/water-alarms/thermostatic-mixing-valve.

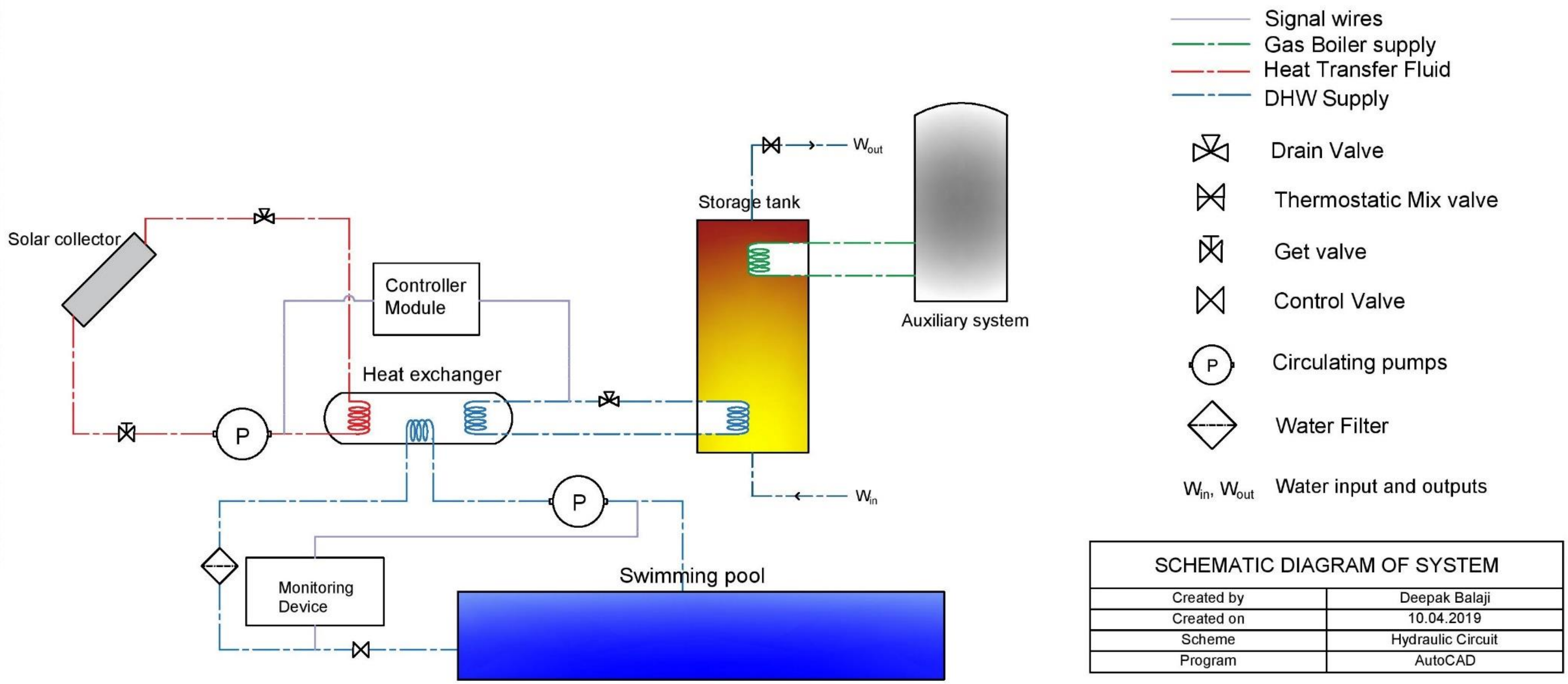
[23] "Watts tools," [Online]. Available: https://www.watts.com/resources/references-tools/t-and-p-relief-valves. [Accessed 2019].

[24] "ARC mechanical," [Online]. Available: https://www.arcmech.com/homeowners/solar-water-heaters/.

[25] "Pump station," [Online]. Available: https://www.archiproducts.com/en/products/caleffi/accessory-for-solar-heating-system-255-pump-station_208989.

[26] "Climate and Energy," [Online]. Available: https://www.mzp.cz/en/emission_trading. [Accessed 2019].

SCHEMATIC DIAGRAM OF SOLAR HEATING SYSTEM



SCHEMATIC DIAGRAM OF SYSTEM	
Created by	Deepak Balaji
Created on	10.04.2019
Scheme	Hydraulic Circuit
Program	AutoCAD